CERES Cloud Algorithm Status & Validation

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F-L. Chang

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P. W. Heck

CIMSS, U. Wisconsin

CERES Science Team Meeting, Newport News, VA

28-30 April 2009

CERES Cloud Activities & Plans

- Prepared & submitted papers on algorithms, validation, science

- Continued validations & development of Ed3 improvements
  - Matched CALIPSO data available just in last few weeks
- Completed Terra Ed2C and Aqua Ed2 through Aug 2007
- Edition 3
  - *Evaluated Beta 1*
  - *Refining Beta 1, added some new changes,*
  - *Need delay to deliver Beta 2*
    - *been slowed down as will be seen later*

CERES cloud-related papers published/accepted/submitted since last STM

• Minnis, P., Q. Z. Trepte, S. Sun-Mack, Y. Chen, D. R. Doelling, D. F. Young, D. A. Spangenberg, W. F. Miller, B. A. Wielicki, R. R. Brown, S. C. Gibson, and E. B. Geier, 2008: Cloud detection in non-polar regions for CERES using TRMM VIRS and Terra and Aqua MODIS data. *IEEE Trans. Geosci. Remote Sens.*, **46**, 3857-3884.

• Waliser, D., F. Li, C. Woods, J. Bacmeister, J. Chern, A. DelGenio, J. Jiang, M. Kharitondov, Z. Kuang, H. Meng, P. Minnis, S. Platnick, W. B. Rossow, G. Stephens, S. Sun-Mack, W. K. Tao, A. Tompkins, D. Vane, C. Walker, and D. Wu, 2008: Cloud ice: A climate model challenge with signs and expectations of progress. *J. Geophys. Res.*, **114**, D00A21, doi:10.1029/2008JD010015 .

• Xie, Y., P. Yang, G. W. Kattawar, P. Minnis, and Y. Hu, 2009: Effect of inhomogeneity of ice crystals on retrieving ice cloud optical thickness and particle size. In press, *J. Geophys. Res.*

• Huang, J., Q. Fu, J. Su, Q. Tang, P. Minnis, Y. Hu, Y. Yi, and Q. Zhao, 2009: Taklimakan dust aerosol radiative heating derived from CALIPSO observations using the Fu-Liou radiation model with CERES constraints. *Atmos. Chem. and Phys.*, accepted.

• Lin, B., P. Minnis, T.-F. Fan, Y. Hu, and W. Sun, 2009: Characterizing radiative properties of low and high clouds in different oceanic cloud regions using CERES data. Accepted, *J. Climate.*

• Lin, B., L. Chambers, B. Wielicki, W. Rossow, Y. Hu, P. Minnis, P. Stackhouse, N. Loeb, W. Sun, G. Potter, Q. Min, G. Schuster, and T.-F. Fang, 2009: Climate perturbation, energy balance, and feedback. *Geophys. Res. Lett.*, submitted.

• Wang, W., J. Huang, P. Minnis, Y. Hu, J. Li, Z. Huang, and J. K. Ayers, 2009: Dust cloud properties and radiative forcing over dust source and remote regions derived from CERES and CALIPSO data during PACDEX. Submitted to *J. Geophys. Res.*

CERES cloud-related papers submitted/ in prep since last STM

• Chepfer, H., S. Bony, D. Winker, G. Cesana, J.L. Dufresne, P. Minnis, C. J. Stubenrauch, and S. Zeng, 2009: The GCM Oriented CALIPSO Cloud Product (CALIPSO-GOCCP). Submitted to *J. Geophys. Res.*

• Minnis, P., S. Sun-Mack, Y. Chen, and Y. Yi, 2009: Comparison of CERES-MODIS and ICESat GLAS cloud amounts. In revision, *J. Geophys. Res.*

• Xi, B., X. Dong, P. Minnis, and M. M. Khaiyer, 2009: A 10-year climatology of cloud cover and vertical distribution derived from both surface and GOES observations over the DOE ARM SGP site. In revision, *J. Geophys. Res.*

• Minnis, P., S. Sun-Mack, D. F. Young, P. W. Heck, D. P. Garber, Y. Chen, D. A. Spangenberg, R. F. Arduini, W. L. Smith, Jr., M. M. Khaiyer, R. Palikonda, M. L. Nordeen, J. K. Ayers, S. C. Gibson, R. R. Brown, E. B. Geier, Y. Takano, and K.-N. Liou, 2009: Cloud property retrievals for CERES using TRMM VIRS and Terra and Aqua MODIS data, *IEEE Trans. Geosci. Remote Sens.*, in preparation.

• Sun-Mack, P. Minnis, Y. Chen, R. F. Arduini, and D. F. Young, 2009, Visible clear-sky and near-infrared surface albedos derived from VIRS and MODIS data for CERES. *IEEE Trans. Geosci. Remote Sens.*, in preparation.

• Trepte, Q. Z, P. Minnis, D. A. Spangenberg, R. F. Arduini, S. Sun-Mack, and Y. Chen, 2009: Polar cloud and snow discrimination for CERES using MODIS data. *IEEE Trans. Geosci. Remote Sens.*, in preparation.

• Yost, C. R., P. Minnis, S. Sun-Mack, and L. Nguyen, Evaluation of CERES-MODIS cumulus and stratocumulus cloud amounts using high-resolution CALIPSO data. *J. Geophys. Res.*, in preparation.

• Sun-Mack, P. Minnis, Y. Chen, S. Gibson, et al. Comparison of CERES-MODIS, CALIPSO, and CloudSat properties. *J. Geophys. Res.*, in preparation.

• Saunders, W. J. Lawrence, J. Storey, M. Ashley, S. Kato, P. Minnis, and D. Winker, 2009: Where is the best site on Earth? Domes A, C, and F, and Ridges B and A. *Ann. Rev. Astronom. Astrophys.*, in preparation.

SANDisk Crash Recovery & Follow-On Work

- Ed3 beta1 delivery of Feb 2008 was all that survived
  - new code written to replace all lost upgrades
  - new IGBP map derived MODIS scene ID product gone
- Ed2 conversion to MAC & IBM cluster computers for DAAC
  - Aqua code & QC codes have been delivered
- Built ISCCP histogram QC package for Ed3 β2,
  - pressure levels changed to ISCCP definitions
- Constructed SSF read package and made a page for displaying SSF monthly averages in manner used for QC plots
- Modified cloud code to catch mismatched NAV & radiance files
- Modified cloud code to read higher res NESDIS snow/ice maps
- Altered QC code to produce netCDF files for GEWEX

SANDisk Crash Recovery & Follow-On Work, 2

- A-Train matched dataset used for algorithm testing/validation
  - rewrote merging and reanalysis code
    - 3 MODIS, 4 CALIPSO, 2 CloudSat datasets
  - Ran 4 months of reduced swath matched dataset to test & refine Ed3 codes, validate Ed2 results (1 mo)
  - developed Google earth tool for displaying pixel level results

    http://earth-www.larc.nasa.gov/~eheckert/googlemap.php
  - developed Google Earth tool to display A-Train & CERES curtains
  - constructed NEWS/ A-Train web page
  - rewrote A-Train DX display package (almost complete)
- Rewrote GLAS analysis code
- Wrote NPP sub-channel/sampling software, delivered to PEATE, accepted
- Added rough crystals & revised CO2 code into Ed 3 β2

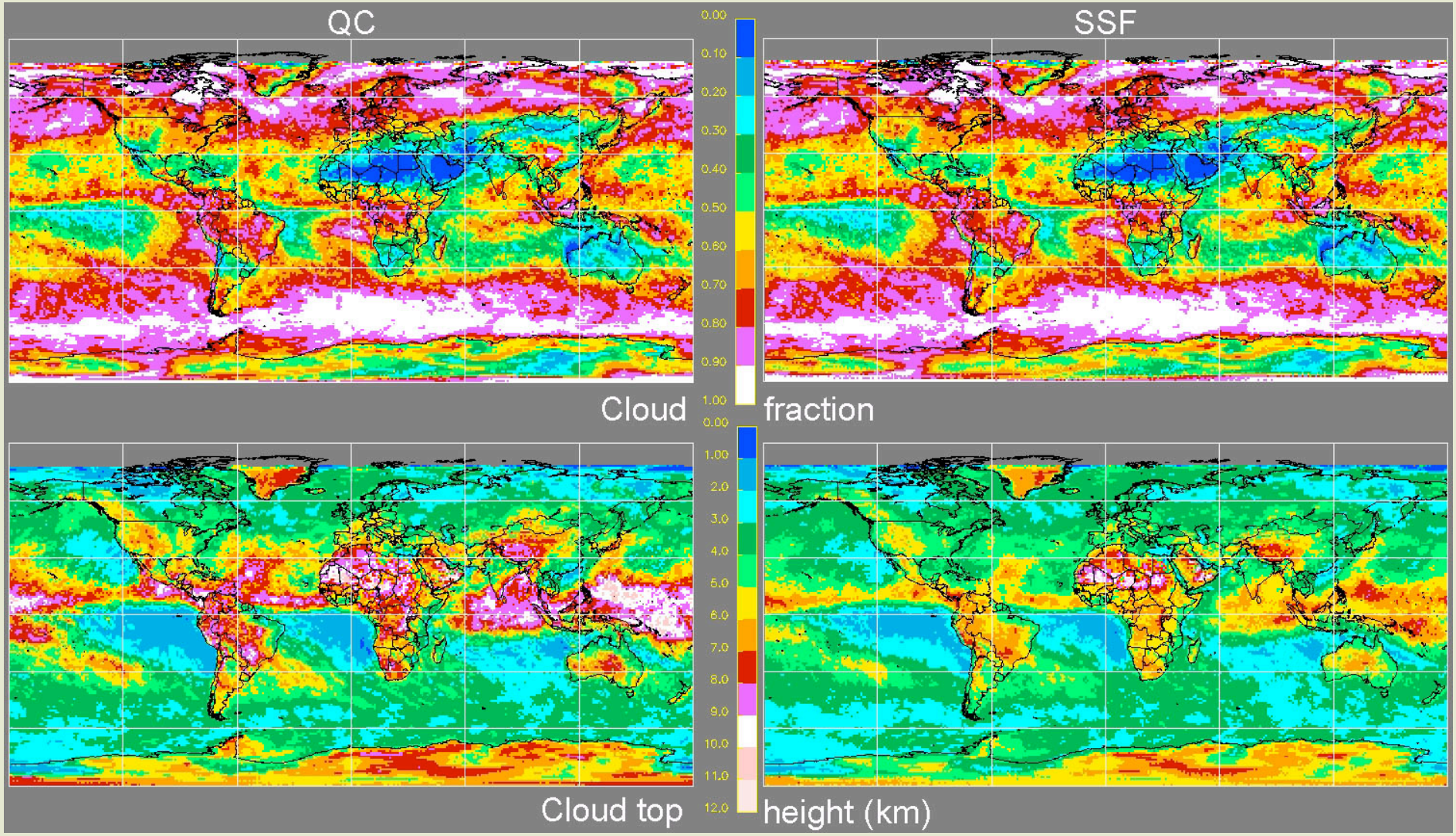
GEOS-5 & Forward Processing

- GEOS-5 still needs a few corrections, waiting for samples to run
- Reprocessing and ahead
  - Dec 97 – Dec 12, after corrected GEOS-5 approved
- New processing, Ed2
  - through August 2007 for Terra & Aqua
  - Ed2-IGBP running with new IGBP map
  - monthly means available through March 2009 with Flash Flux

CERES SSF Monthly Averages & Clouds QC

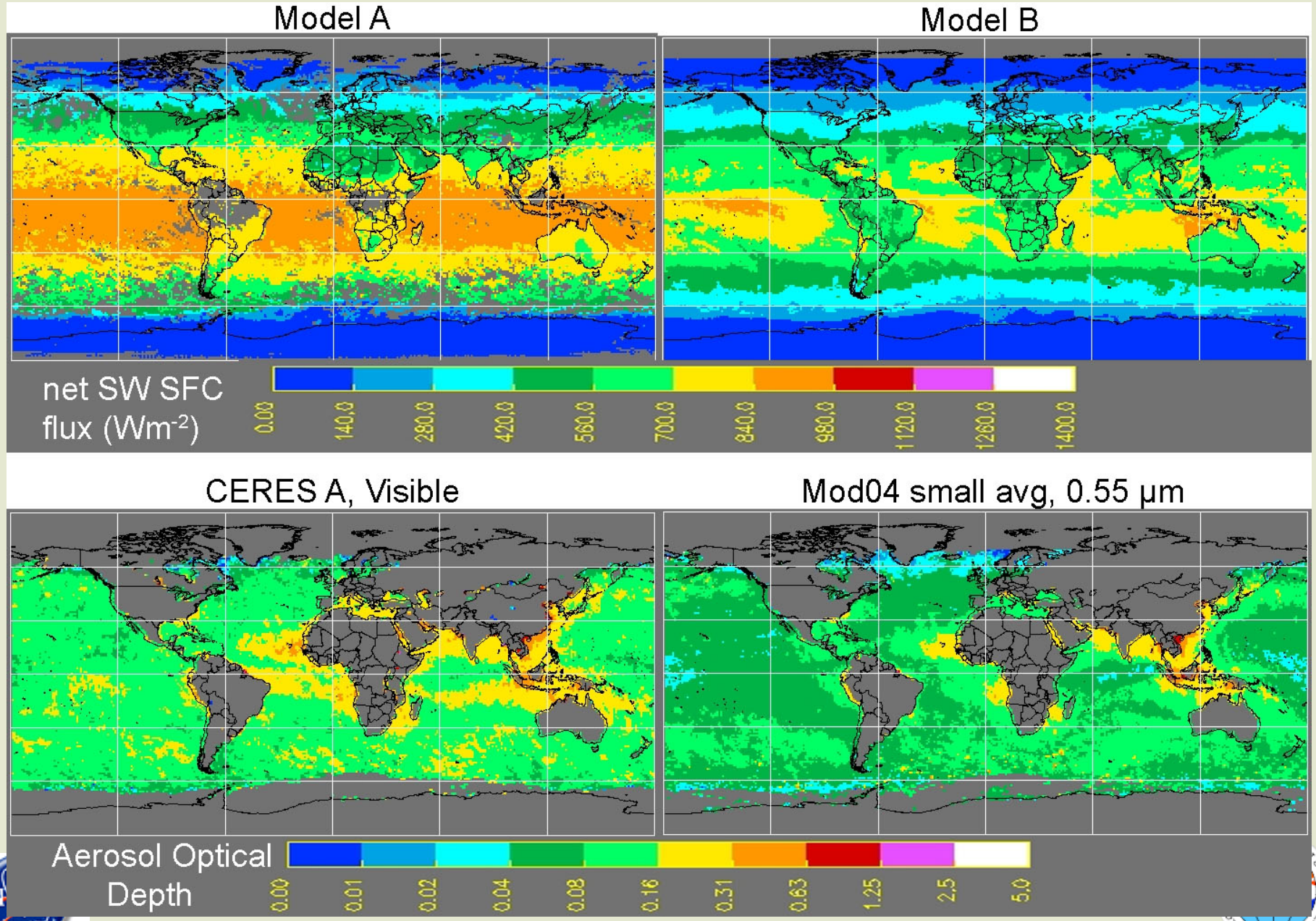
http://lposun.larc.nasa.gov/~cwg/aqua/aqua.html

SSF vs QC Cloud Properties, October 2004, Day



- Cloud fractions very close
- Mean cloud heights tend to be much lower for SSF, except in Sc regions

SSF Radiative & Aerosol Properties, October 2004, Day



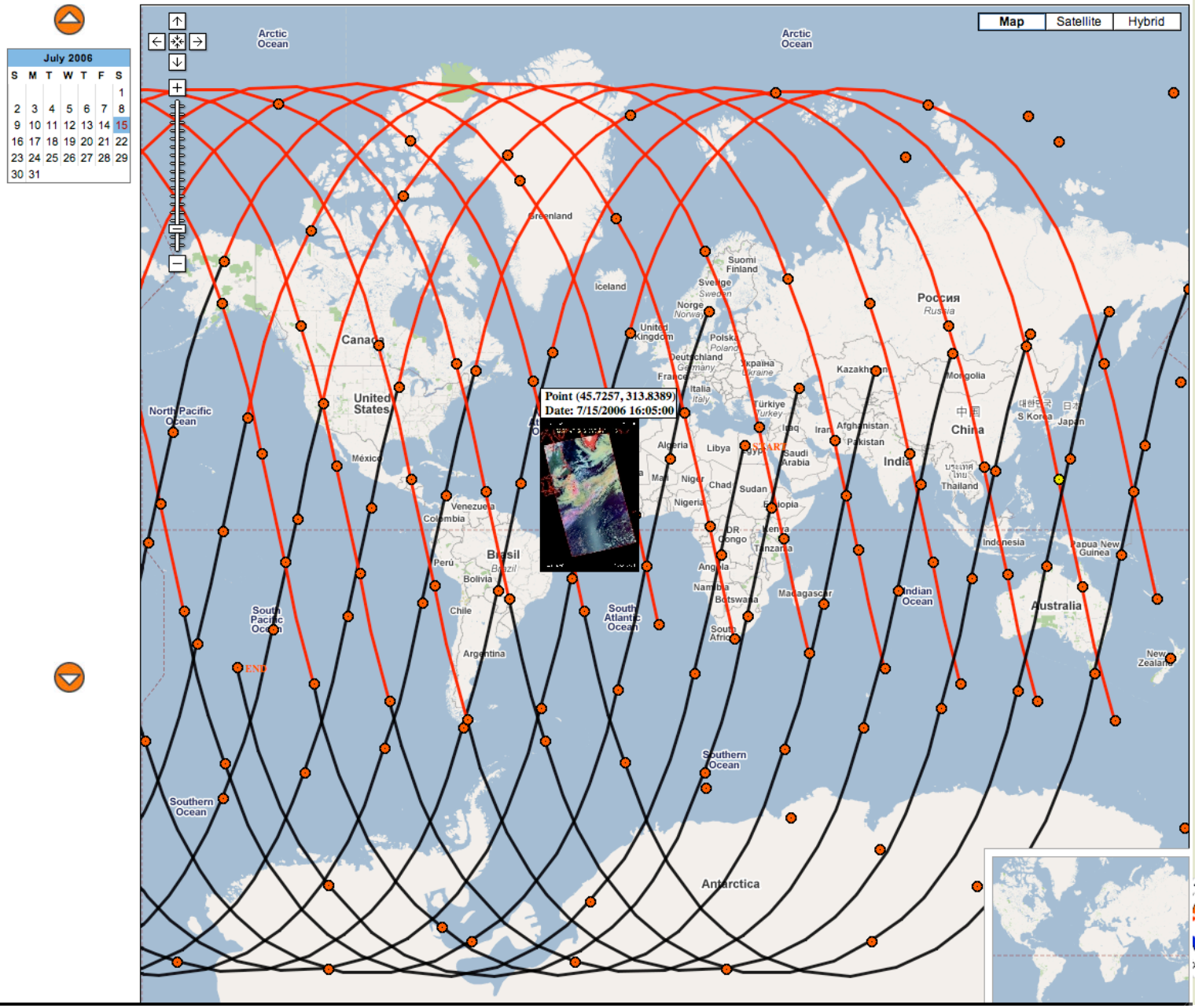
Google Earth Displays of Pixel Level Results by Granule

Preliminary

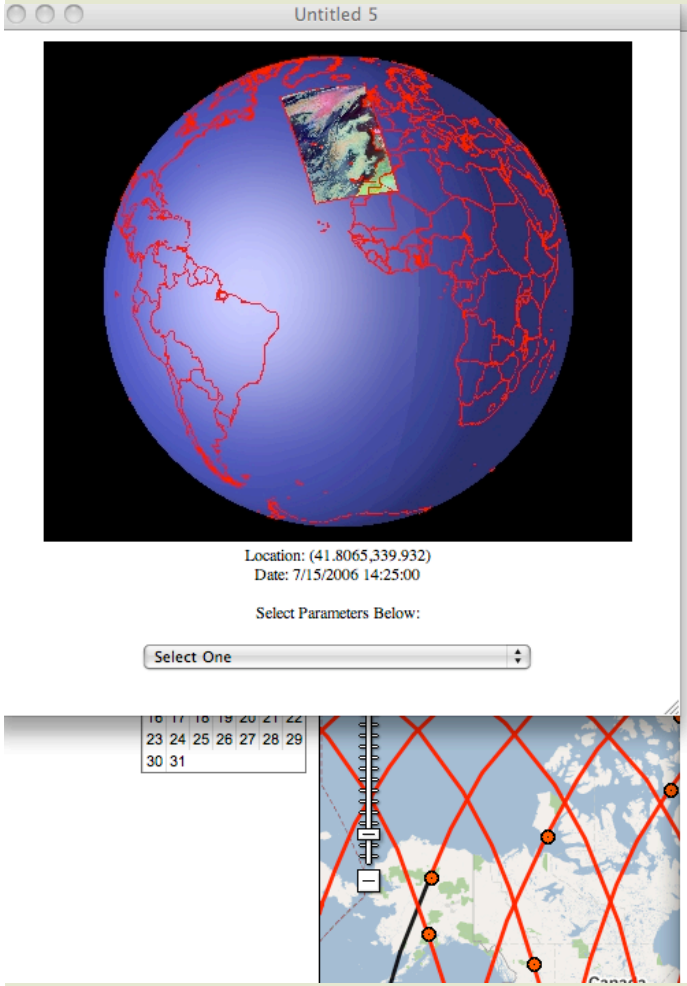
http://earth-www.larc.nasa.gov/~eheckert/googlemap.php

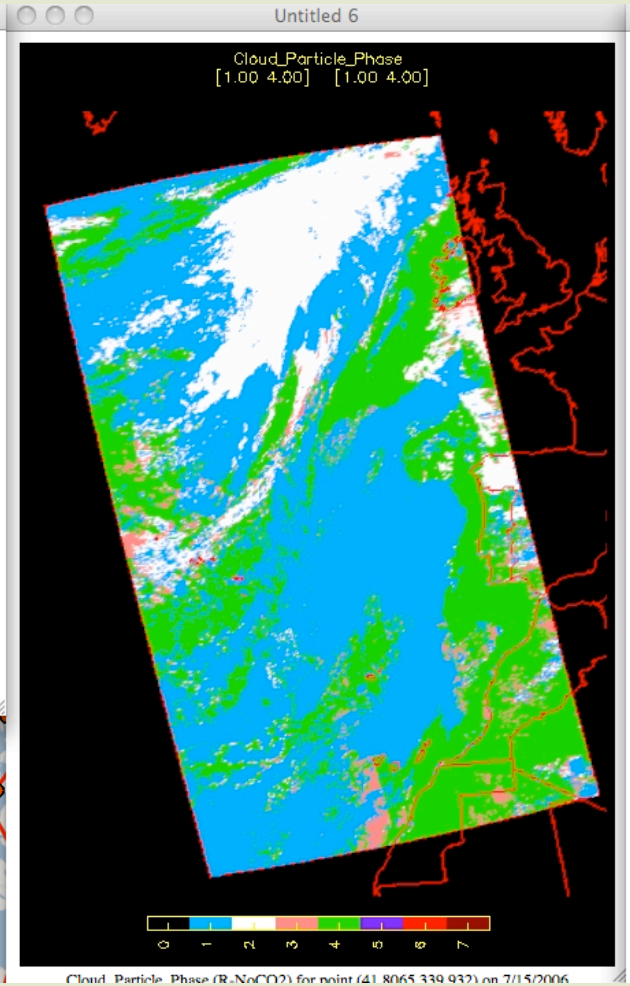
Aqua-MODIS Ed3Beta2 Imagery

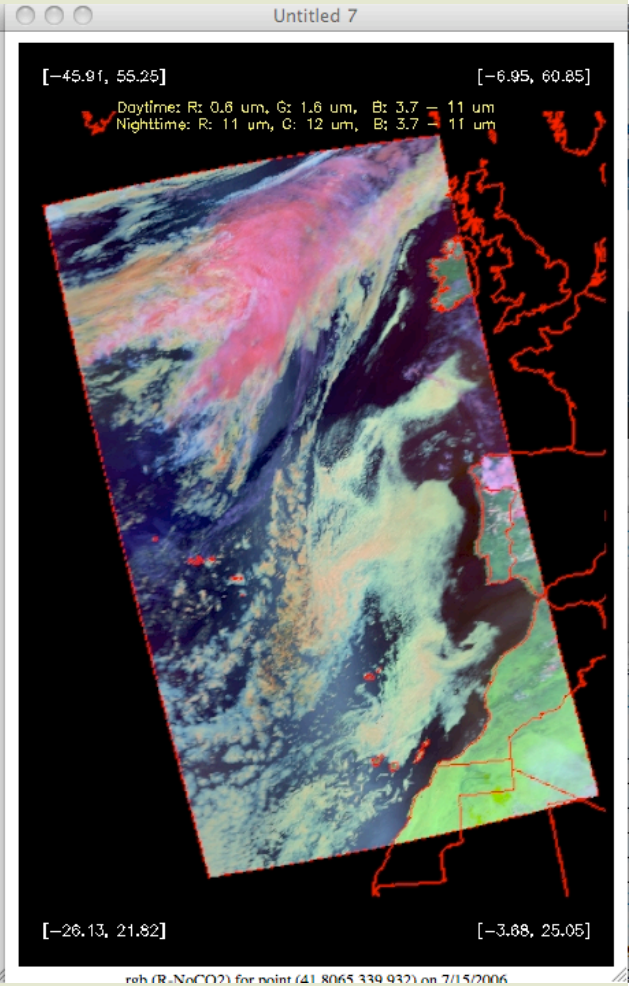
Please click on a date from the calendar on the left.
Currently viewing: 7/15/2006



Select images of any parameter desired, from the list



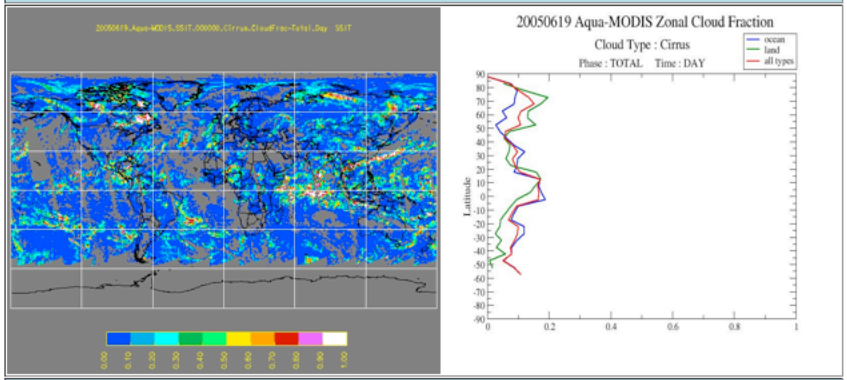
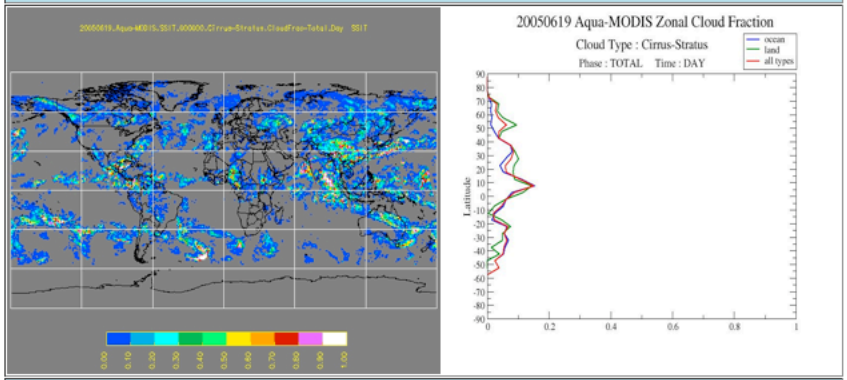
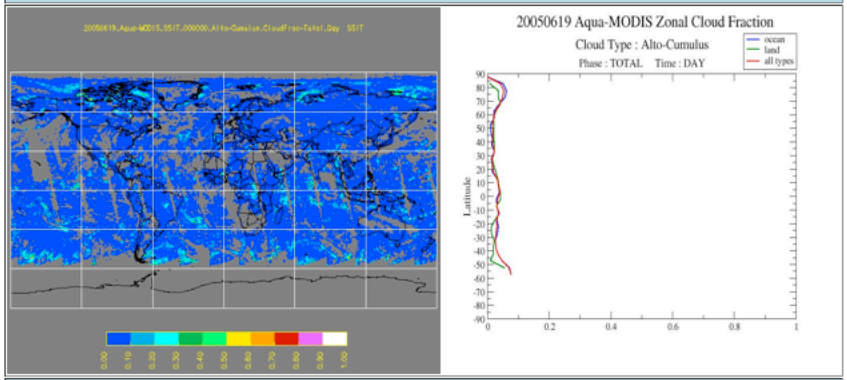
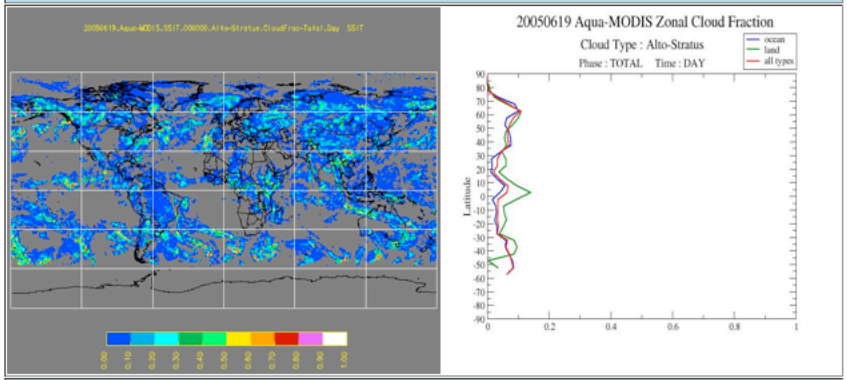
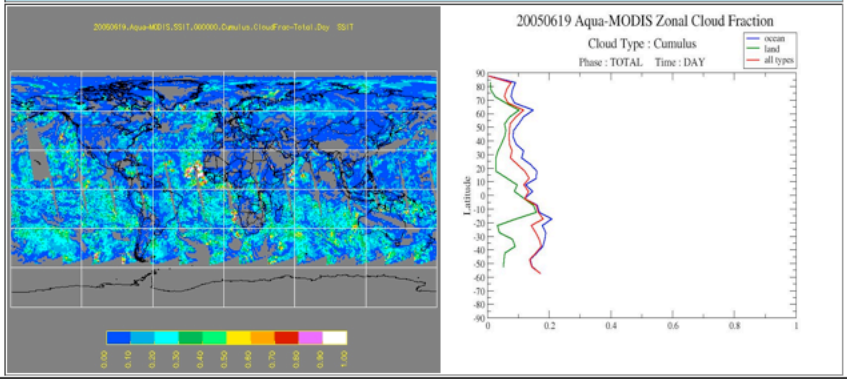
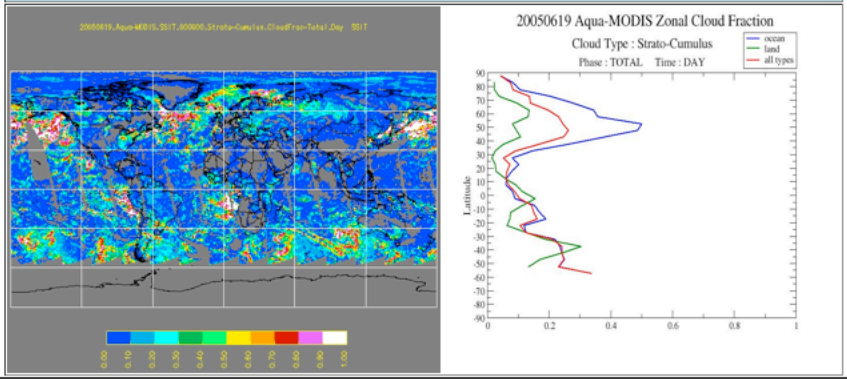


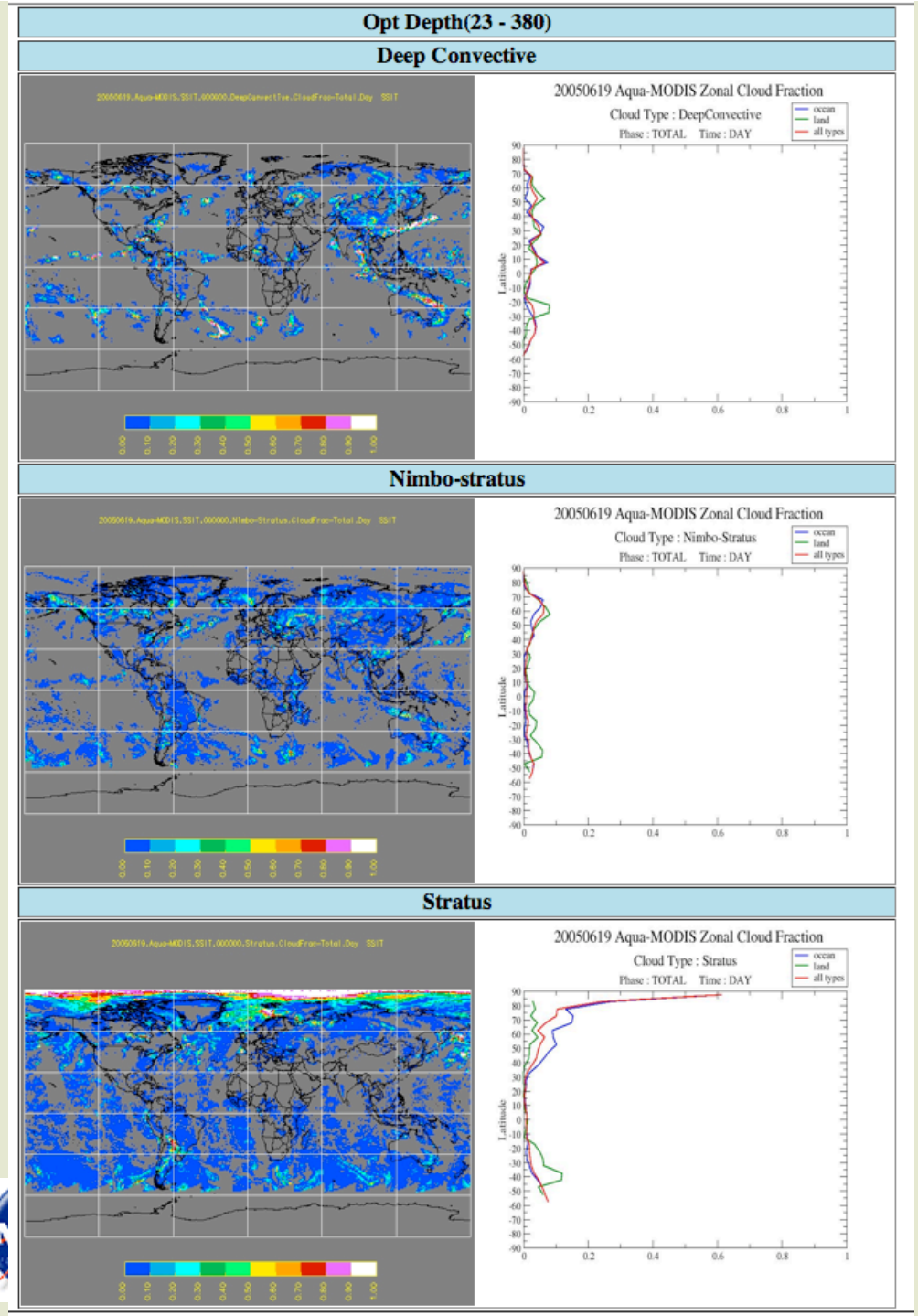


CERES ISCCP-D2-like Results

Date 20050619 Satellite Aqua-MODIS Time Day Phase Total Parameter List Cloud Fraction Display

Main Page

Pressure	Opt Depth(0.0 - 3.6)	Opt Depth(3.6 - 23)
High	Cirrus	Cirrus-stratus
10-440(mb)		
Mid	Alto-cumulus	Alto-stratus
440-680(mb)		
Low	Cumulus	Strato-cumulus
680-1000(mb)		

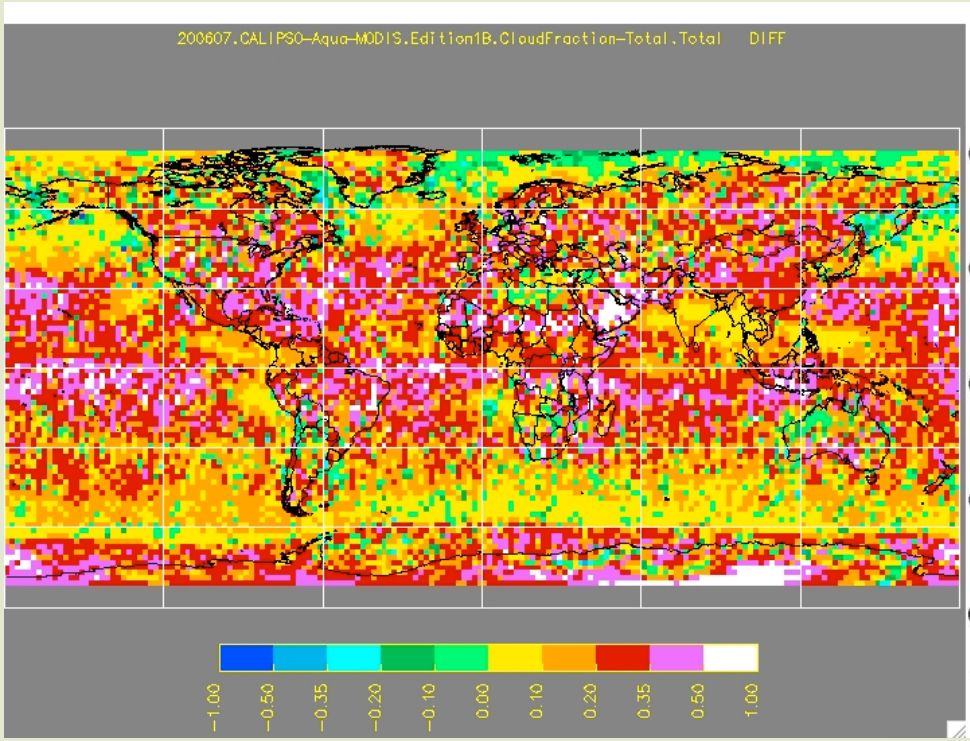


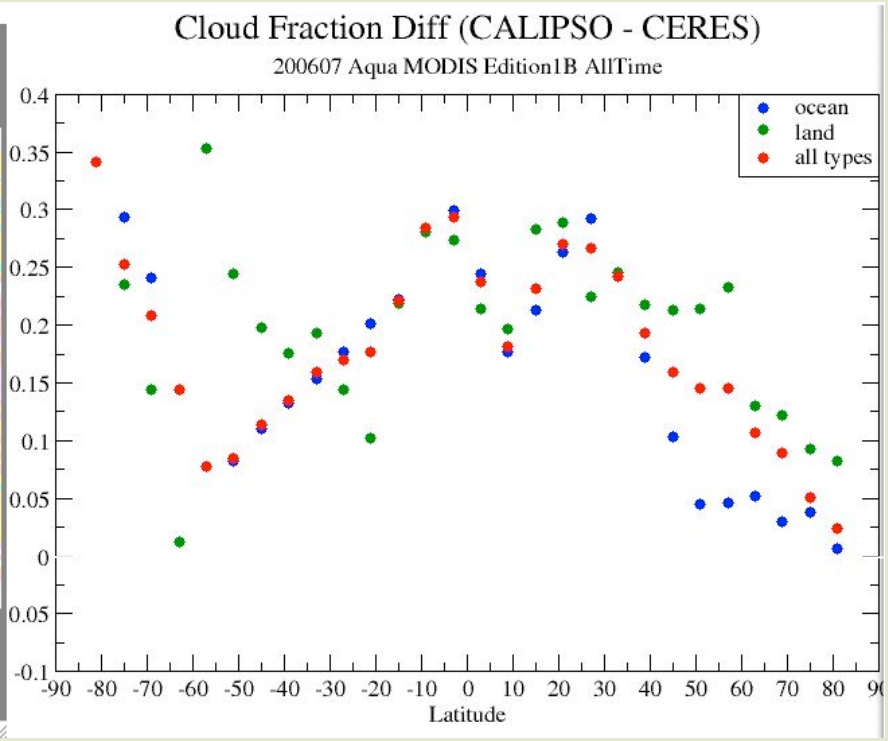
ISCCP-like Cloud Property Distributions

- Currently only available for one day
- Software complete and ready for Ed3
- Run Ed2

BACKGROUND

Cloud Fraction Difference, July 2006: CALIPSO - CERES





In general, CERES appears to need more clouds -

Mostly polar night & tropics (high & low)

Ed3 Beta1 Cloud Code Changes

- **Cloud Mask Changes**

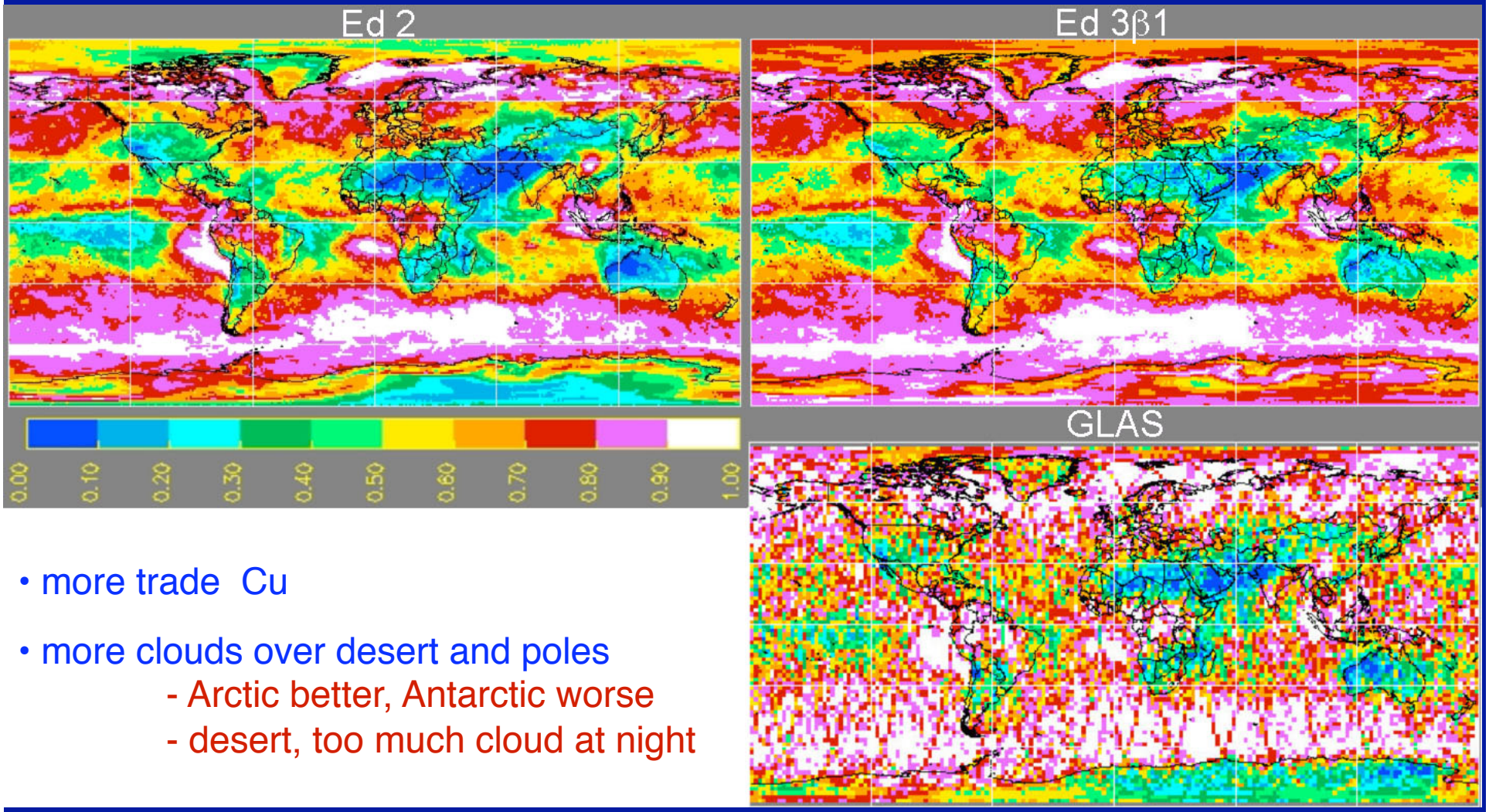
Non-polar Day

- *improved dust detection using IR BTDs, ref ratios*
- additional low cloud check for SZA > 70°
- better snow tests for high elevation/melting snow
- refined cloud shadow tests
- reduced misclassifications along coasts
- sunglint definition changed from prob > 2% to prob > 10%
- new warm cloud tests in sunglint

Non-polar Night

- attempted reduction in polar-nonpolar discontinuity
- added low/inversion cloud detection test based on sfc emis thresholds
- reduced T3.7-T11 STD (threshold) by 0.5 K
- refined snow & thin cirrus detection tests

Terra, Ed2 vs Ed 3 beta1, October 2003



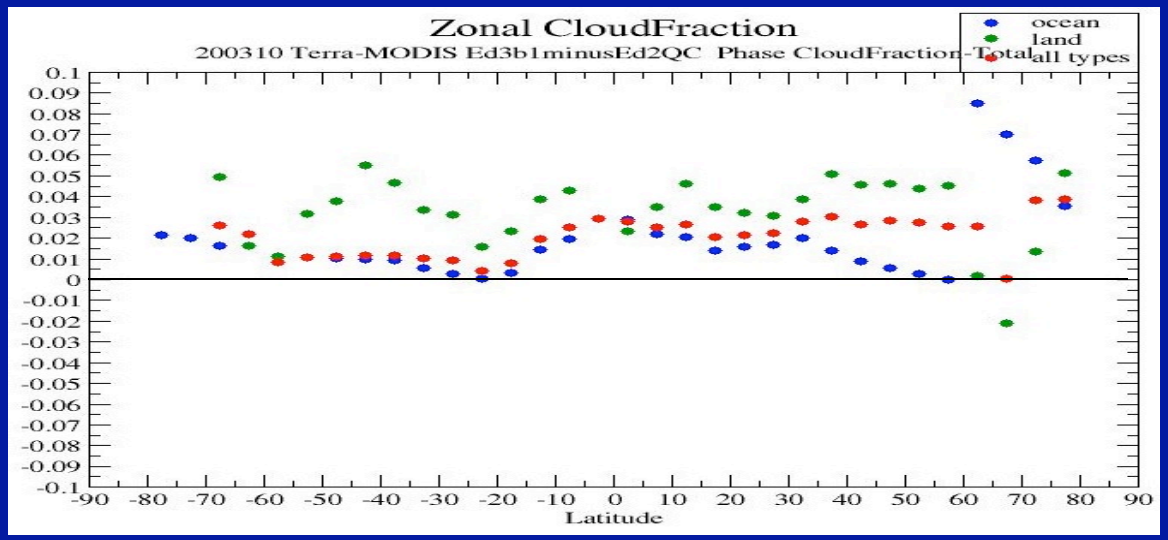
- more trade Cu
- more clouds over desert and poles
  - Arctic better, Antarctic worse
  - desert, too much cloud at night

- Need more adjustment of mask, especially at night

Zonal Cloud Fraction differences

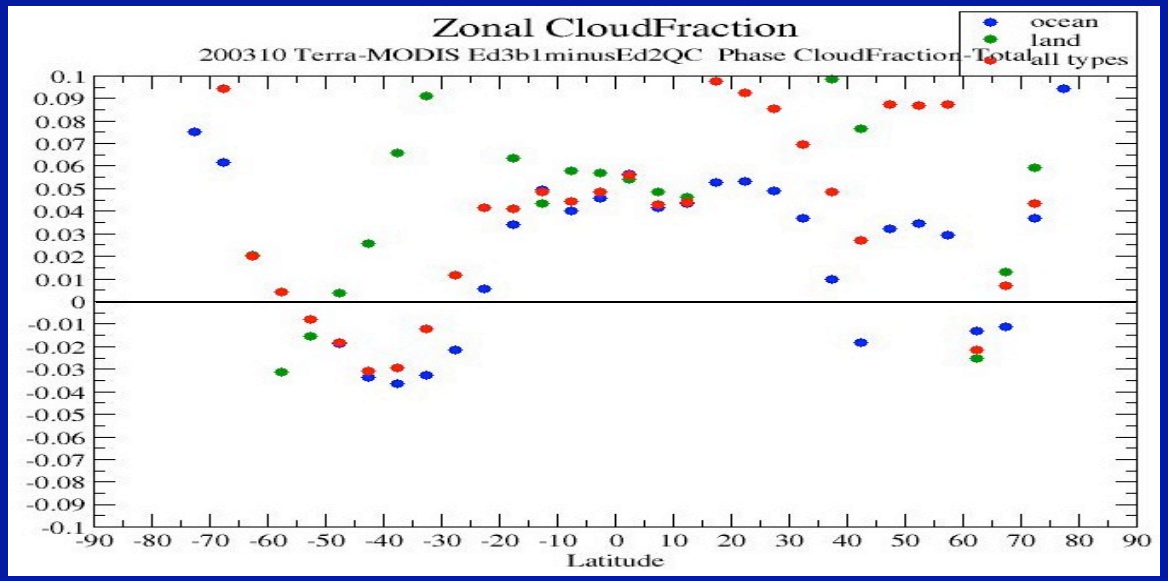
Terra MODIS, October 2003

Daytime Ed3 – Ed2



Daytime cloud fraction
Increases for all latitudes

Nighttime Ed3 – Ed2



Southern hemisphere
-60 lat < -30,
(need investigation!)

Desert & polar regions
need more work

Similar results for Aqua

Cloud Property differences between Ed β1 – Ed2
Terra MODIS, July, 2006, non-polar

Terra Aqua (1 day)	Ocean	Land	Total
Daytime (global)	1.7 3.3	4.4 2.8	2.8 3.2
Nighttime (global)	2.4 3.8	8.7 11.6	4.5 5.9

Polar Day	1.3%
Polar Night	17.5%

Highlights of CERES cloud mask changes in Ed3 Beta2

1. Daytime non-polar (all B cld, all B clr, C1, C2, C3, C4, and C6 tests)

- Increase the low clouds detection over ocean, both in sun glint and non-sun glint regions
- Better discrimination of low clouds and dust over desert regions and over oceans, especially in sun glint region
  (added strong_dust_reg_Flag, and ratio of 0.47/2.1 test over desert)
- Improved thin cirrus detection using new 1.38-μm test (more no retrievals)

2. Daytime Polar:

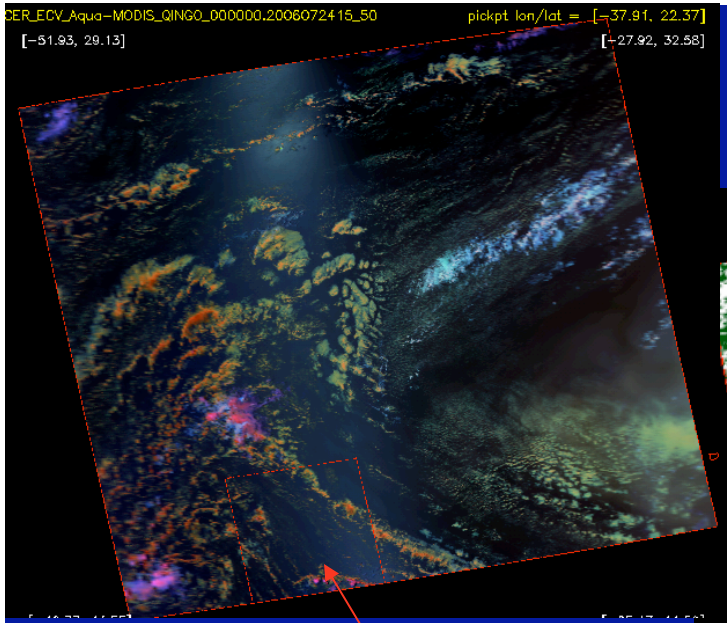
- Included additional ice clouds test to better distinguish ice surface with ice clouds
- Modified polar region definition to solely rely on snow, ice and IGBP maps in order to reduce discontinuity. After examining results, will change it back.

3. Nighttime non-polar

- Better nighttime low clouds and snow surface differentiation (all B clr E2, and E5)
- Remove sfc emittance dependence test for low cloud detection over desert and land

Better Dust and low Clouds in Sun Glint

Aqua July 24, 2006, UTC 1550



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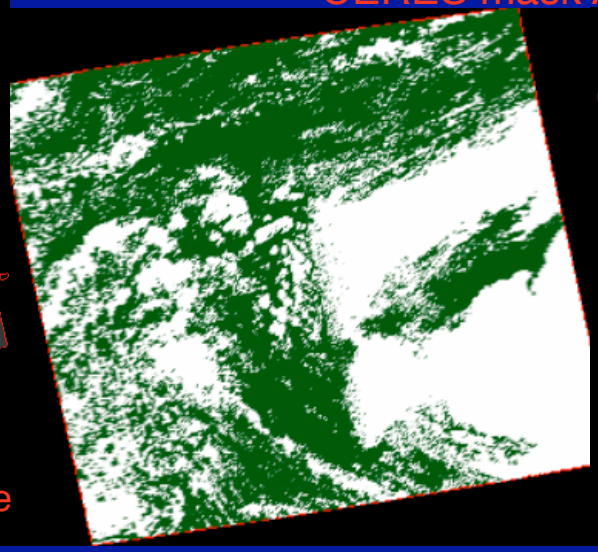
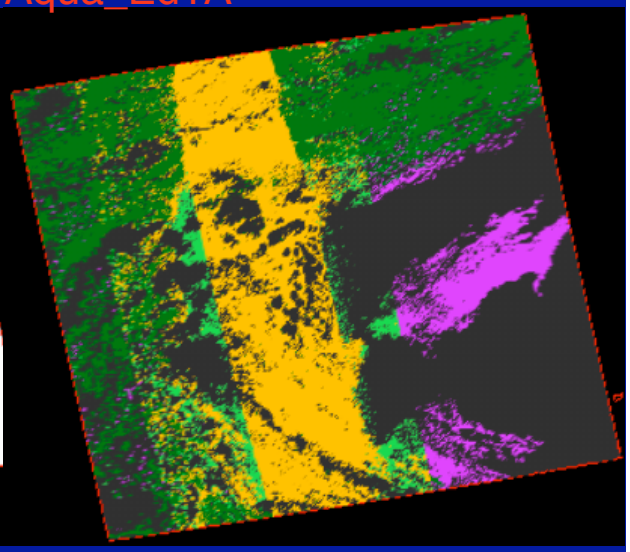
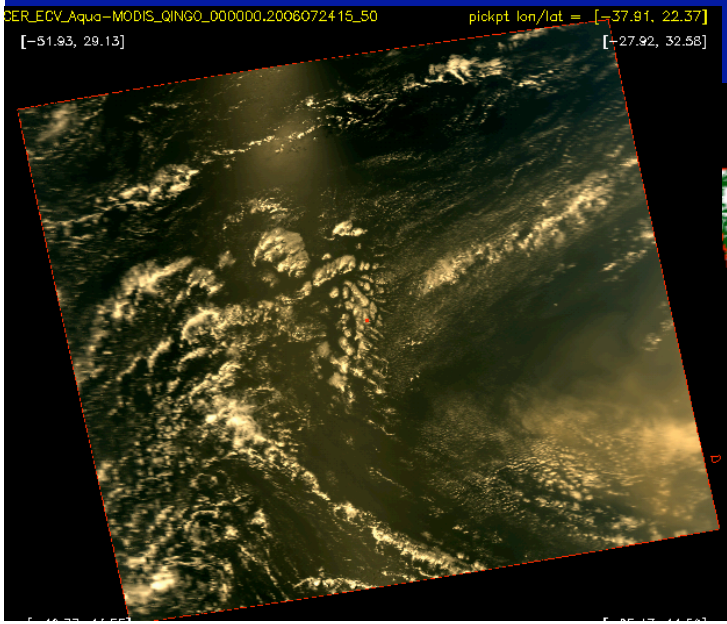
CERES mask Aqua_Ed1A

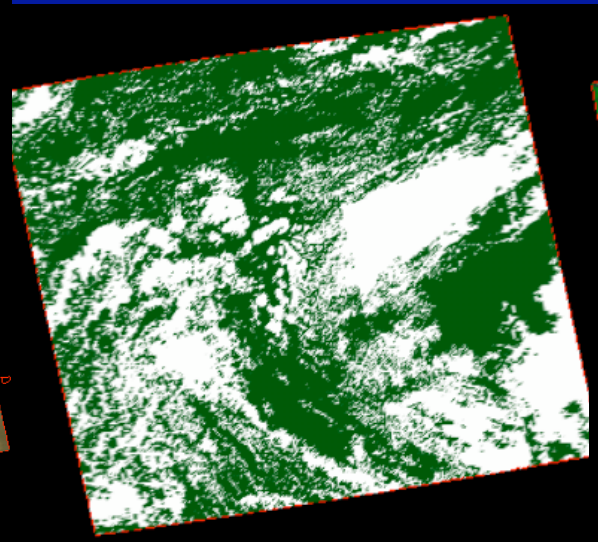


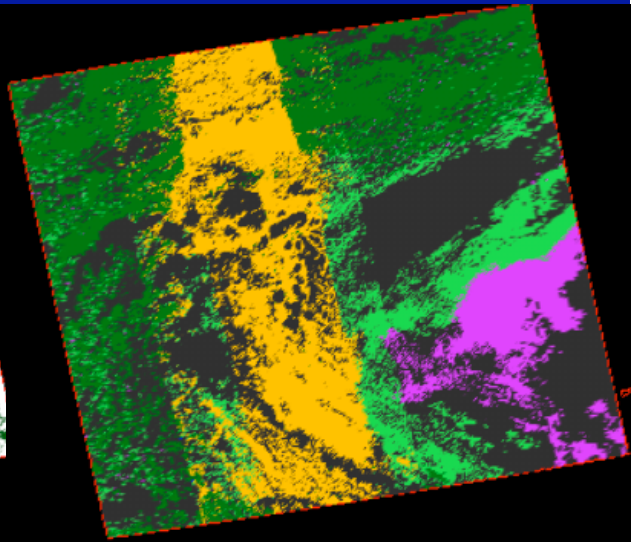


MODIS True-color image

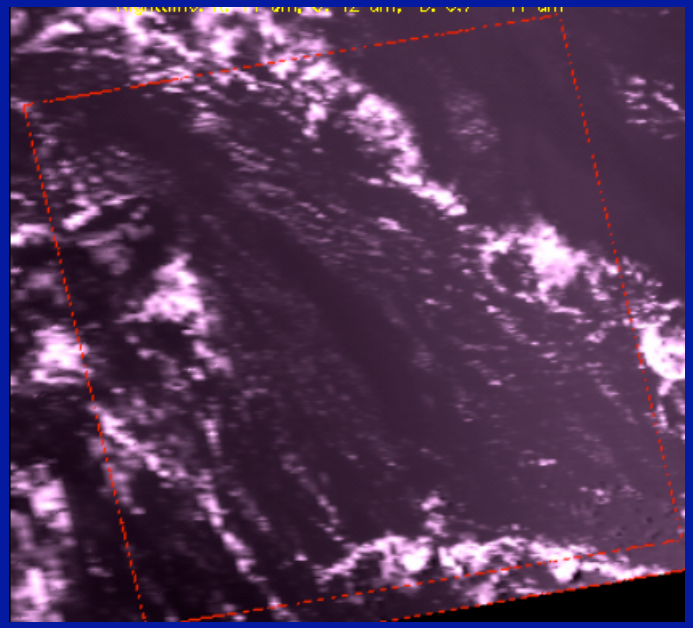
CERES mask Aqua_Ed3



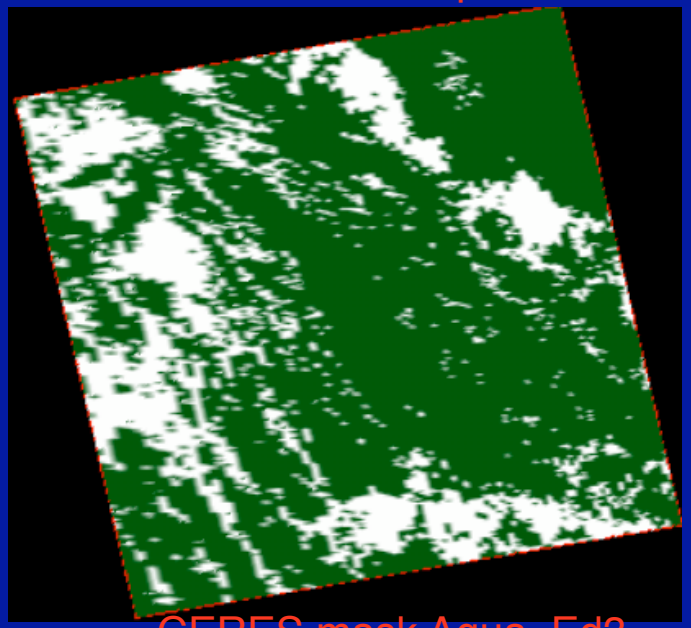




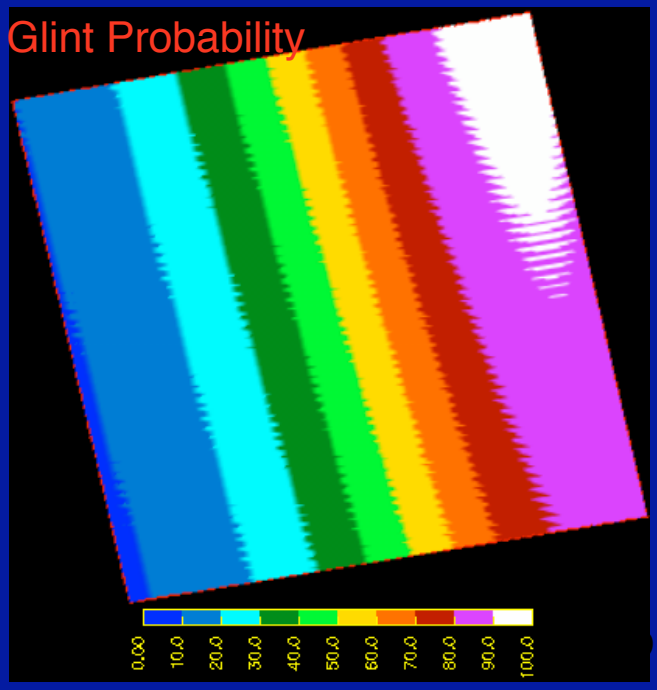
MODIS 0.65 image



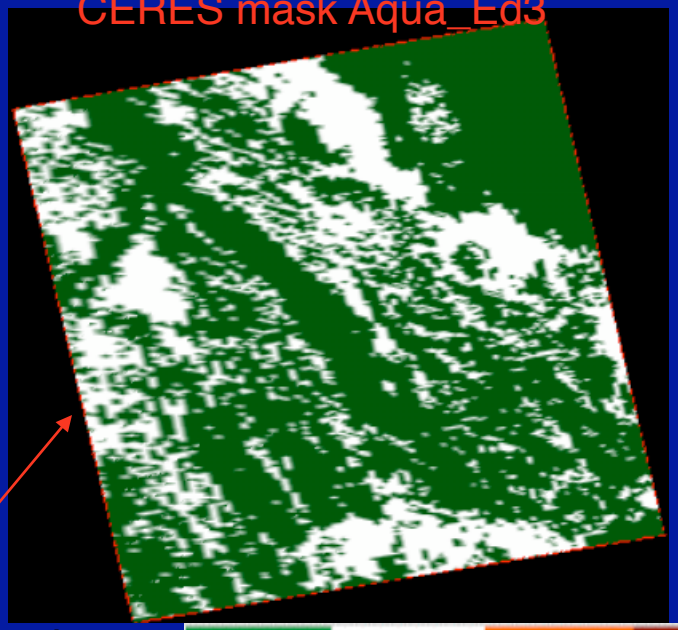
CERES mask Aqua_Ed1A



Sun Glint Probability



CERES mask Aqua_Ed3

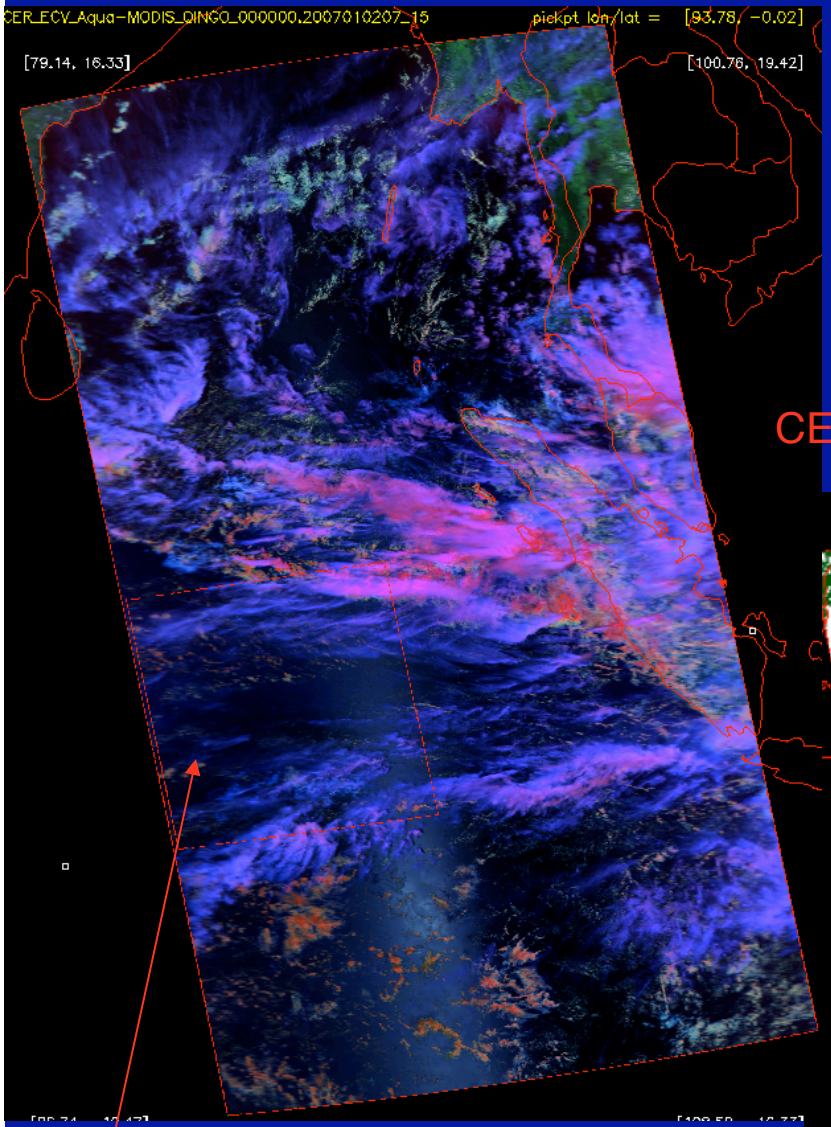


re low clouds

Increased Thin Ci Detection over Ocean

Aqua January 2, 2007, UTC 0715_0720

MODIS RGB image



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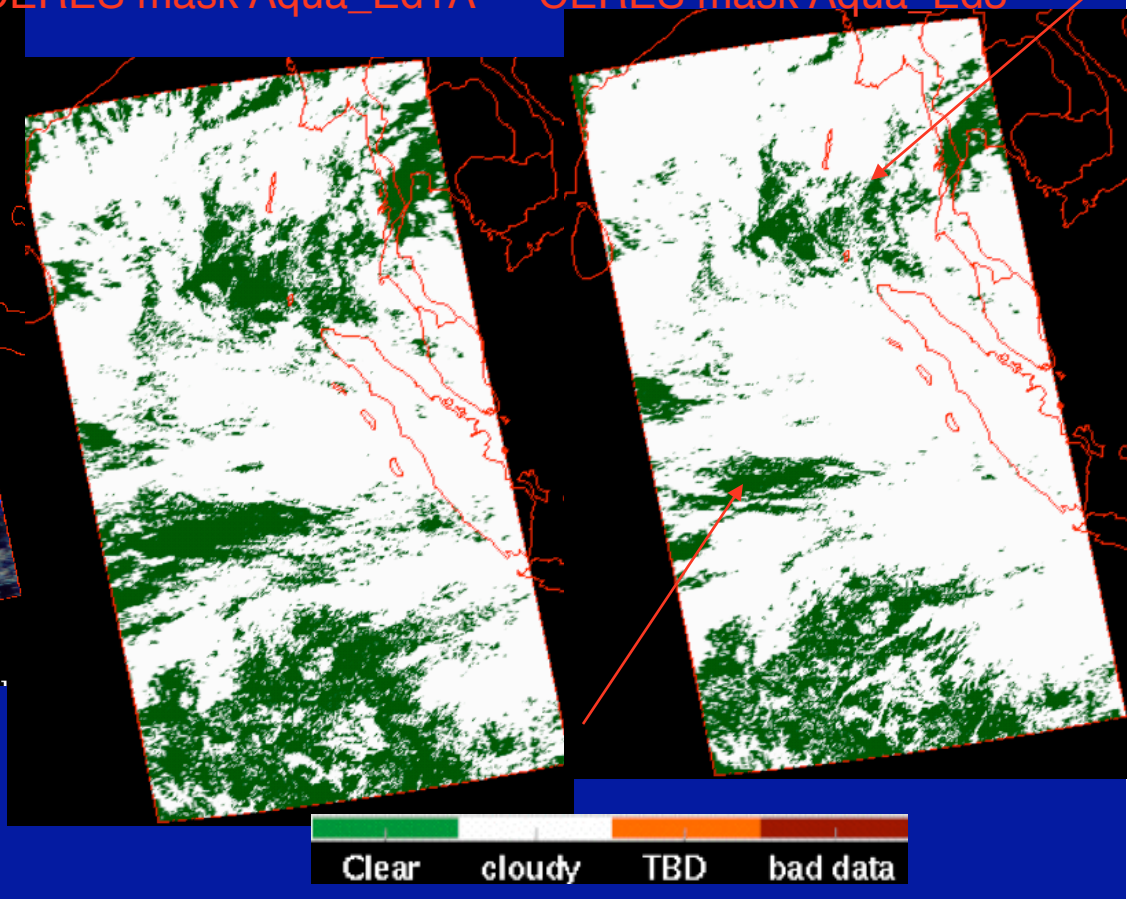
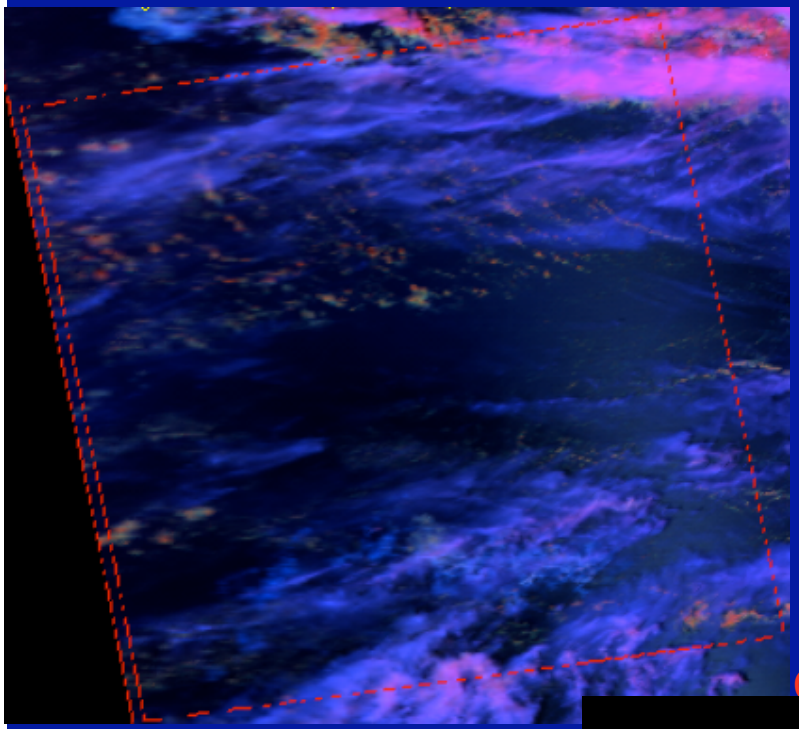
CERES mask Aqua_Ed1A

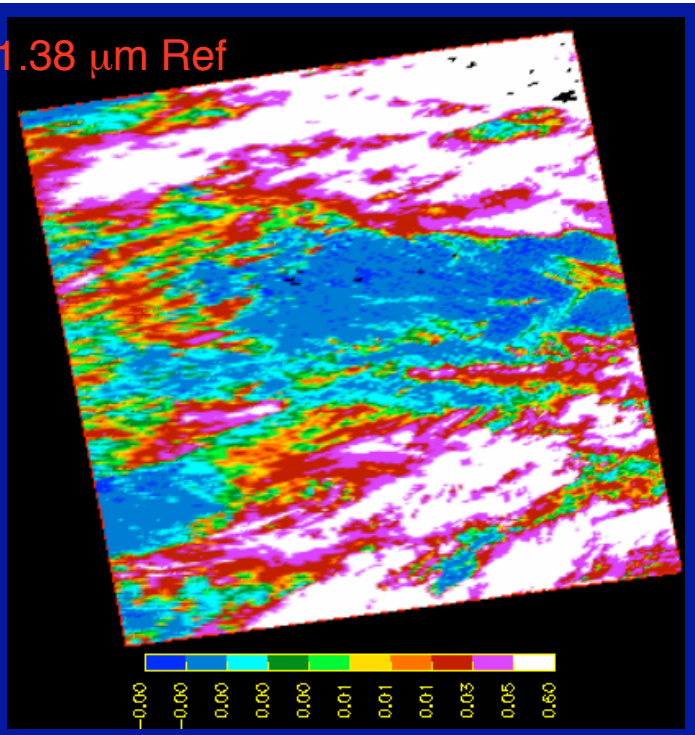
CERES mask Aqua_Ed3



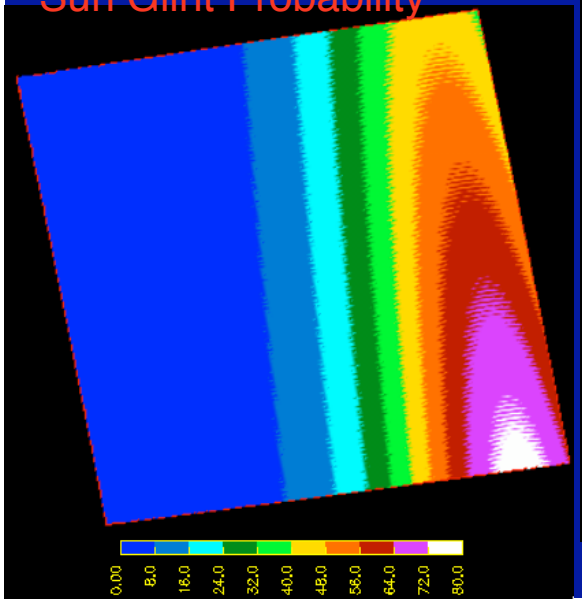
20070102 0715_0720



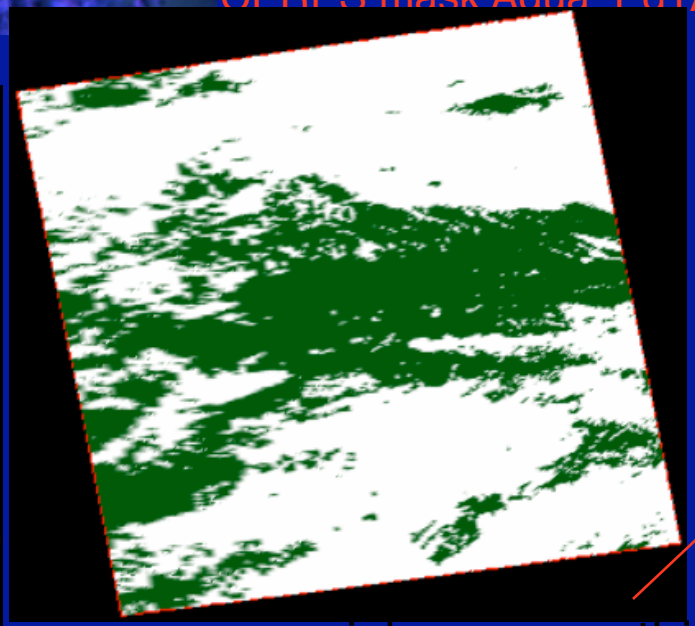
Aqua 1.38 μm Ref



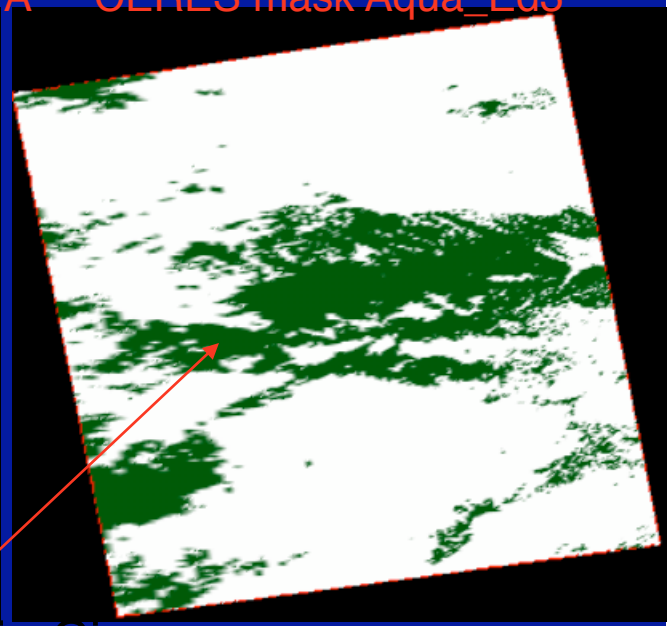
Sun Glint Probability



CERES mask Aqua_Ed1A



CERES mask Aqua_Ed3

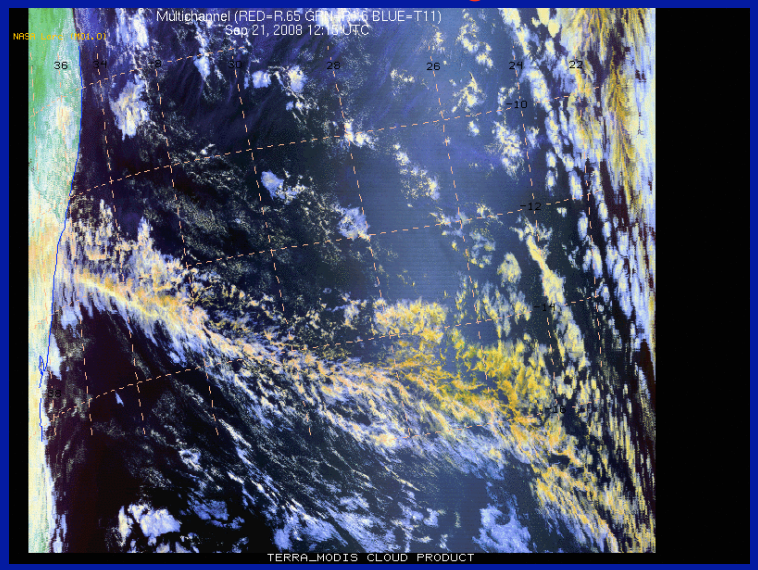


pick up more thin Ci

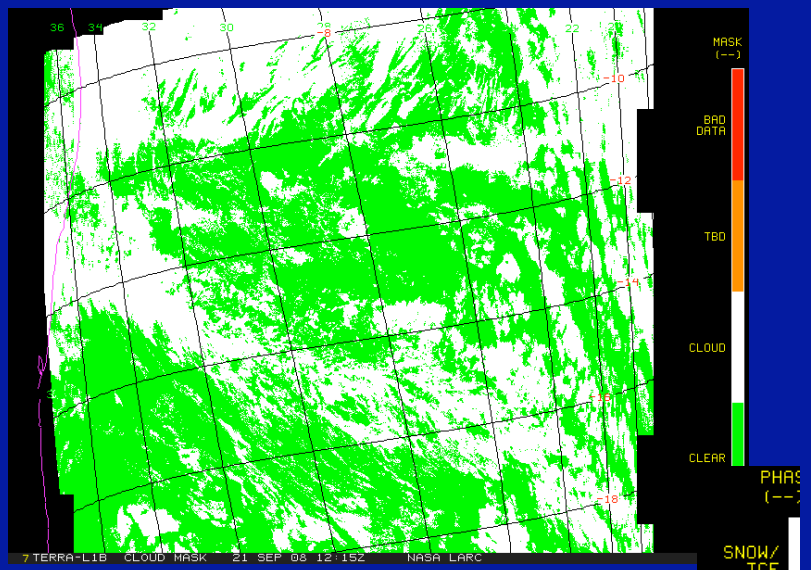
Ed3 Thin Ci Detection and VISST no Retrieval

Terra, September 21, 2008, UTC 1215

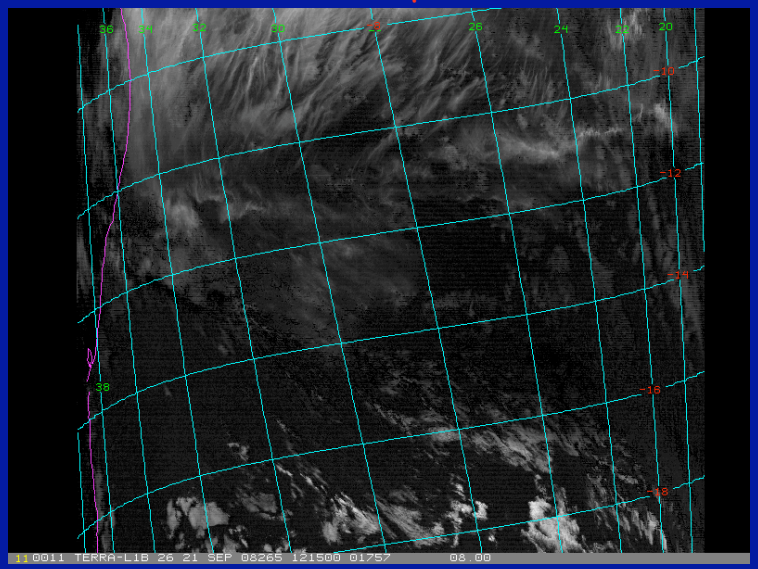
MODIS RGB image



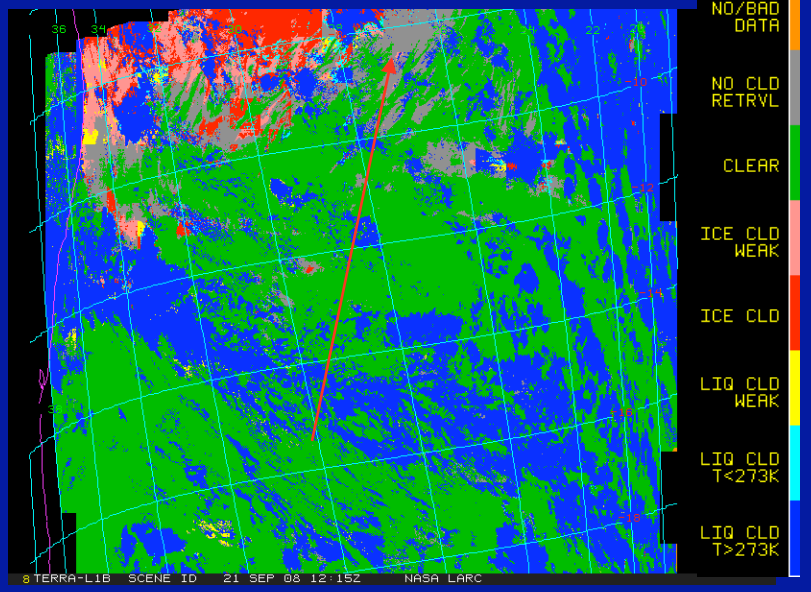
CERES mask Terra_Ed3



Terra 1.38 μm Ref



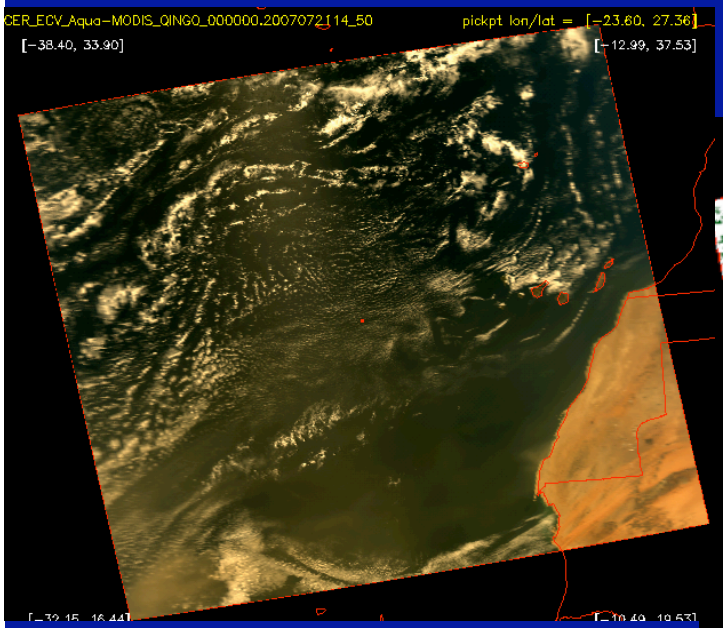
Particle Phase



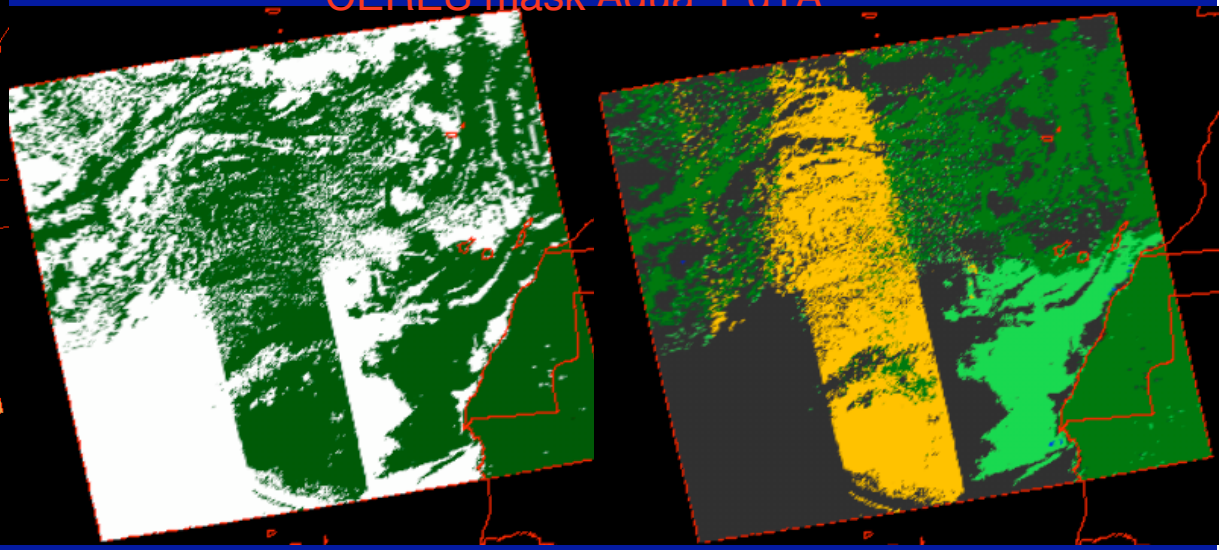
Dust and low Clouds in Sun Glint

Aqua July 21, 2007, UTC 1450

MODIS True-color image



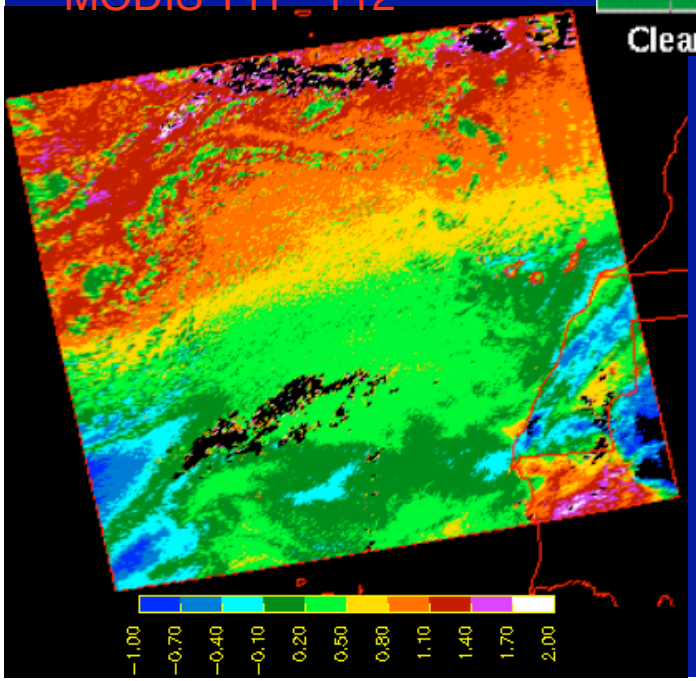
CERES mask Aqua_Ed1A



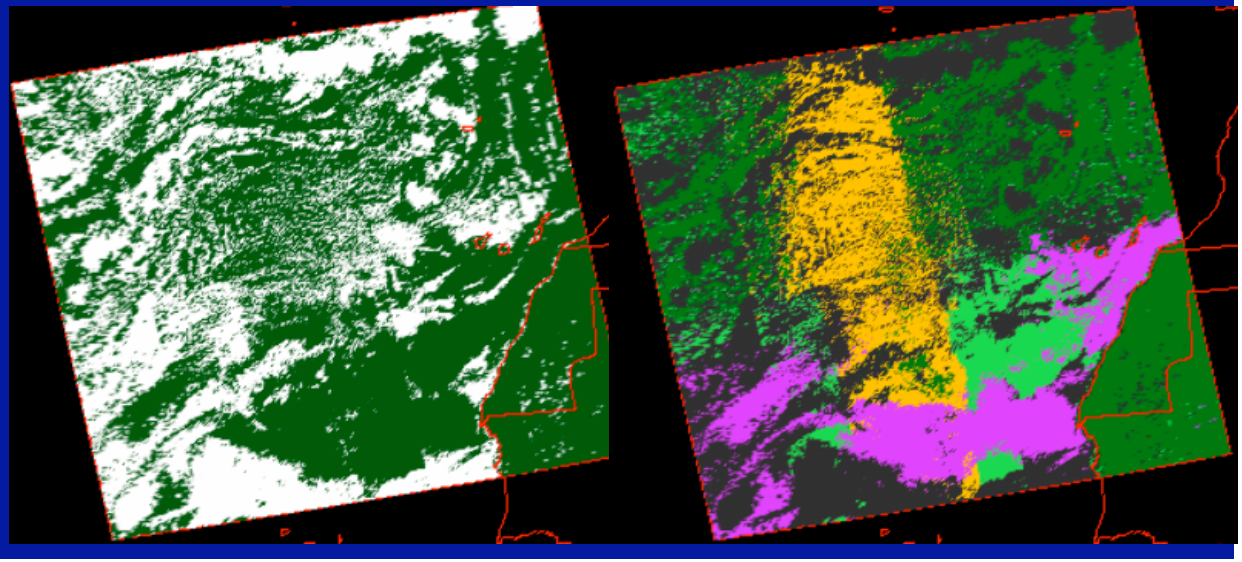
Clear cloudy TBD bad data

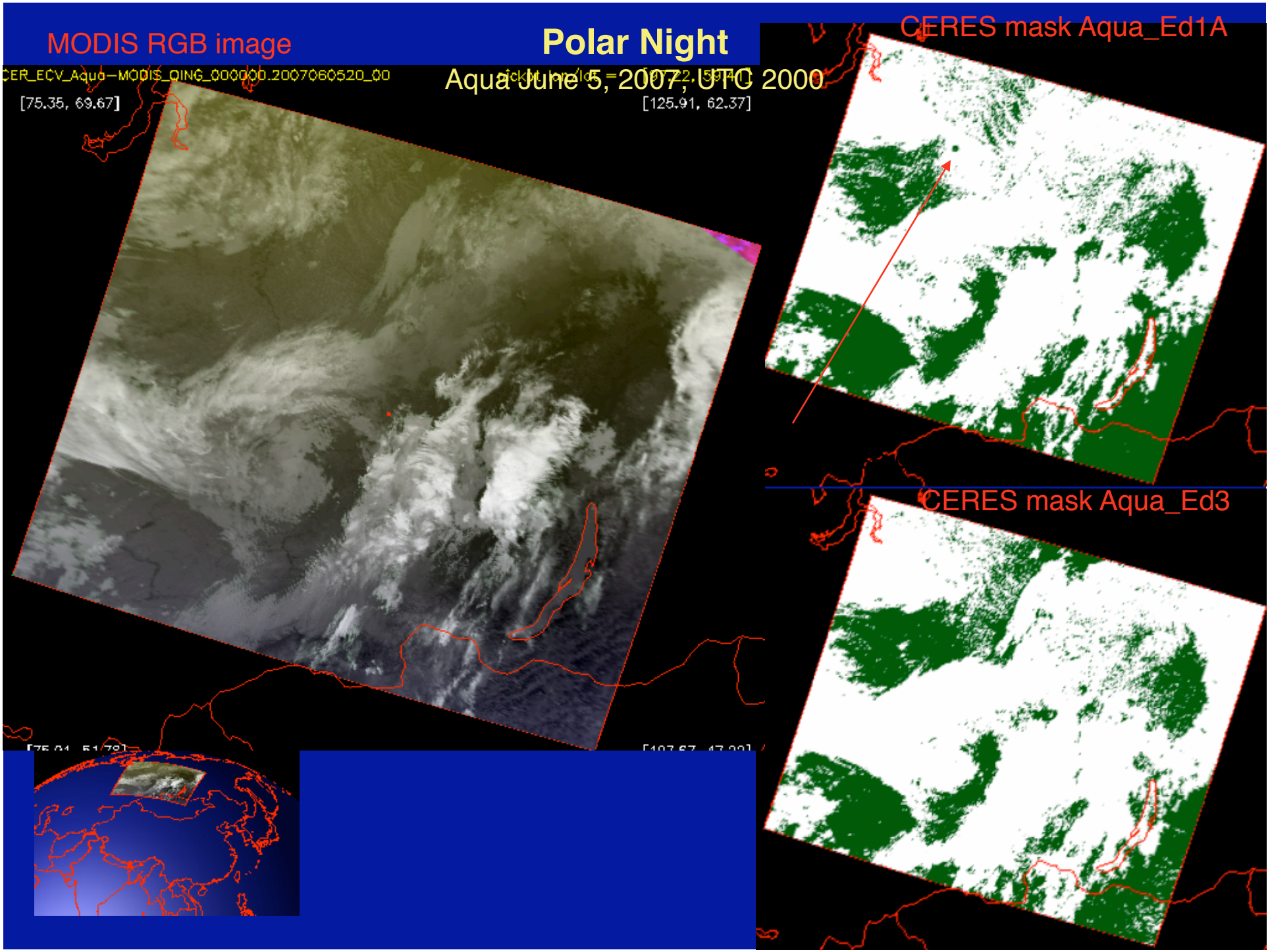
good weak smk fire snow glint shdw arsl else

MODIS T11 - T12



CERES mask Aqua_Ed3




MODIS RGB image
Polar Night
Aqua June 5, 2007, UTC 2000
CERES mask Aqua_Ed1A
CERES mask Aqua_Ed3
[75.35, 69.67]
[125.91, 62.37]

Cloud Fraction Summary

- Total CERES nonpolar underestimate relative to CALIPSO is ~0.18

- Phase determination for SL semitransparent clouds ~80% accurate
  - probably much better during daytime

- 75% of missed cloud cover is semitransparent (0.145)
  - *25% is thin ice clouds mainly with $\tau < 0.3$ (0.035)*
    - not much chance for reliable detection
      - *difficult to make a retrieval*
  - *75% is thin water cloud*
    - *65% has $\tau < 0.3$ (0.07)*
    - *85% has $\tau < 0.5$ (0.093)*

- Remaining missed cloud cover has $\tau > 1$
  - *most likely low clouds at night and large solar zenith angles*
    - small IR contrast
      - multilayered clouds cancel some cloud IR BTD signals
      - IR BTD signals cancelled near terminator (T3.7 – T11)
      - VIS signals ambiguous

How to improve low cloud detection for $\tau > 0.3$?

- Tighten thresholds
  - Ed3 $\beta 1$ low cloud fraction increased over ocean by ~ 0.02

- Daytime, use high resolution (e.g., 250-m) VIS channels to detect subpixel cloud cover
  - examined reality of these low tau clouds
  - We found a bug in the CALIPSO cloud fraction
    it will be fixed in next released

- Use additional channels (8.5, 13.3 μm)

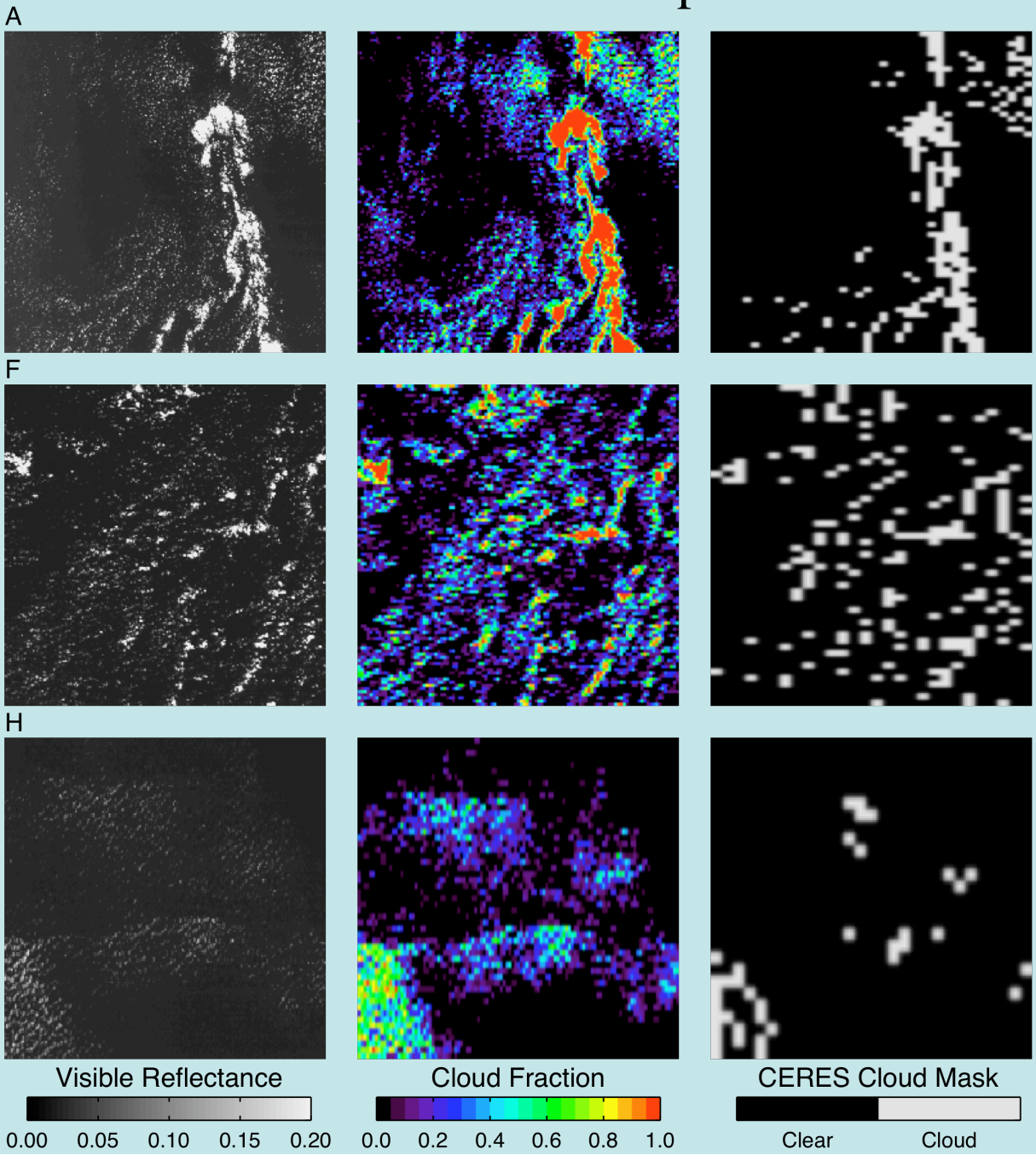
250-m cloud mask comparison

- Use 250-m MODIS visible reflectance to assess Aqua-CERES cloud amounts
  - Based on the derivative of the reflectance frequency distribution (DTM)
  - Use Wielicki & Parker Landsat threshold
  - Apply to every 1-km MODIS pixel

- Compare with CERES and CALIPSO
  - CERES 1-km retrievals
  - CALIPSO 1/3 km & 1 km resolution, high confidence only

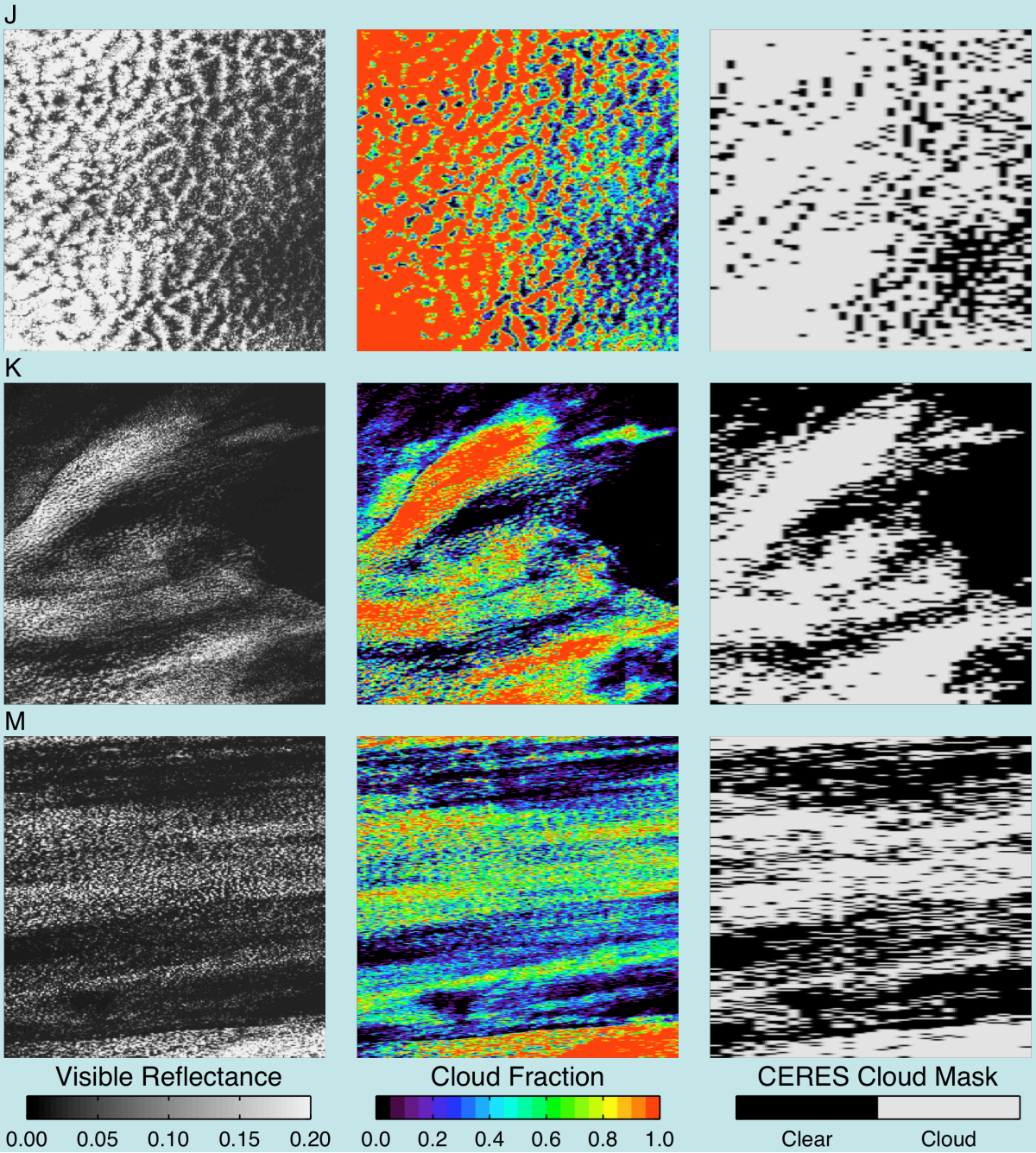
- Compare CERES with CALIPSO all confidence & high confidence

Mask Comparisons for Cumulus



- Many pixels have cloud fractions < 0.30
- CERES misses many of these low fraction pixels
- CERES generally has higher cloud fraction values, especially for Scu

Mask Comparisons for Stratocumulus



- Many pixels have cloud fractions ~ 0.60
- CERES detects all high fraction pixels
- CERES generally has higher cloud fraction values, especially for Scu

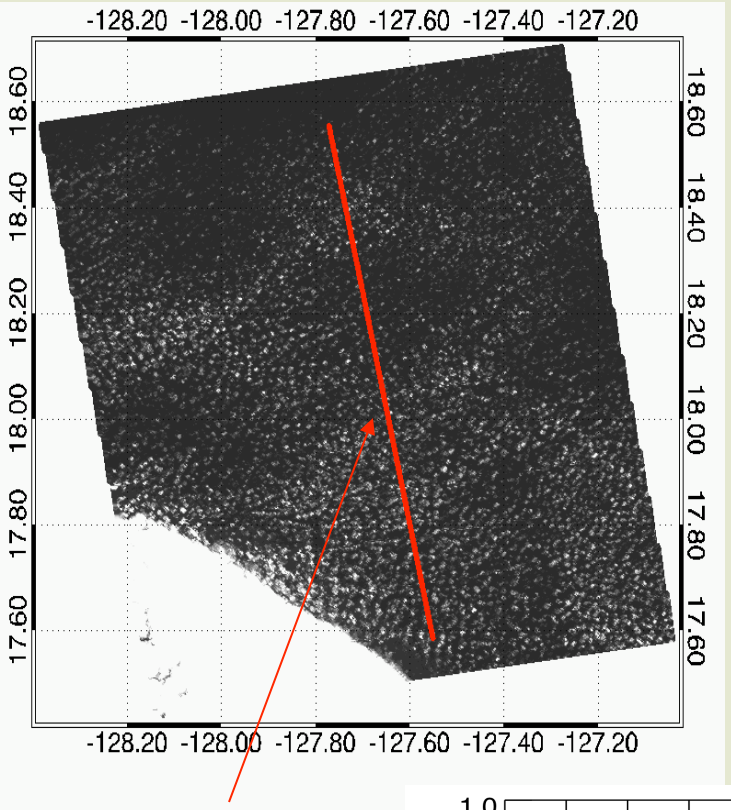
Mask Comparisons Summary

Scene	DTM Rclr	W&P Rclr	DTM Cloud Fraction	W&P Cloud Fraction	CERES Cloud Fraction
A	0.045	0.045	0.16	0.15	0.10
F	0.035	0.030	0.15	0.19	0.13
H	0.035	0.030	0.10	0.16	0.05
J	0.055	0.045	0.68	0.75	0.81
K	0.035	0.030	0.42	0.48	0.51
M	0.030	0.025	0.46	0.58	0.51
All Cu					
Mean	0.040	0.034	0.19	0.26	0.21
Std. Dev.	0.004	0.005	0.09	0.12	0.16
All Sc					
Mean	0.045	0.038	0.50	0.57	0.63
Std. Dev.	0.012	0.010	0.12	0.12	0.12
All scenes					
Mean	0.043	0.036	0.37	0.43	0.45
Std. Dev.	0.009	0.008	0.19	0.20	0.25

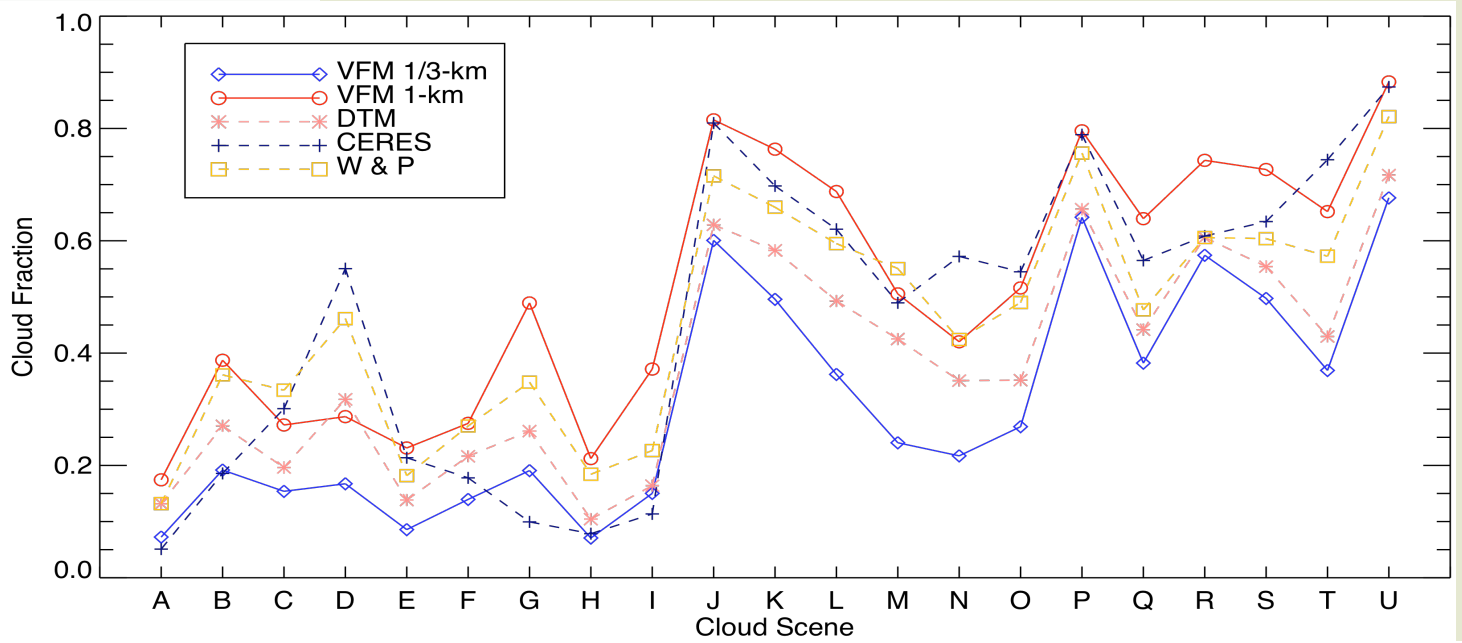
- DTM thresholds slightly > W&P thresholds
- CERES Cu amounts between DTM & W&P (9 cases)
- CERES Sc amounts > W&P > DTM (12 cases)

Cloud Fractions

- Examine cloud fractions along CALIPSO track for same 21 cases
- Matched data from CERES, Aqua-MODIS, and CloudSat to CALIPSO track



- CERES close to 1/3 km for Cu, 1 km for Sc
- DTM between 1/3 & 1 km
- W&P close to 1 km for Cu & Sc
- 1/3 km much less than 1 km



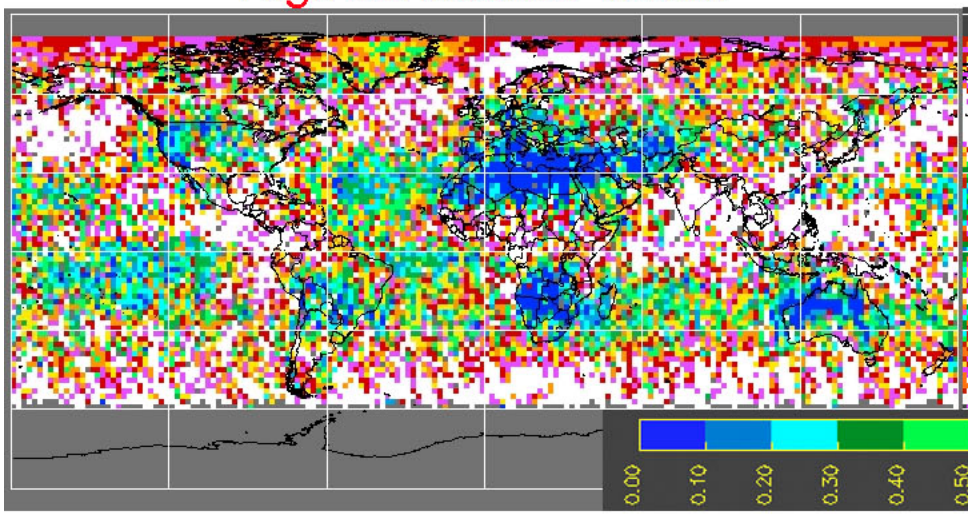
Along-track Cloud Fractions

Scene	DTM Rclr	W&P Rclr	DTM Cloud Fraction	W&P Cloud Fraction	CERES Cloud Fraction	VFM 333-m Cloud Fraction	VFM 1-km Cloud Fraction
Mean	0.040	0.034	0.20	0.28	0.20	0.14	0.30
Std. Dev.	0.004	0.005	0.07	0.11	0.15	0.05	0.10
All Sc							
Mean	0.045	0.038	0.52	0.61	0.66	0.44	0.68
Std. Dev.	0.012	0.010	0.12	0.12	0.12	0.16	0.14
All scenes							
Mean	0.043	0.036	0.38	0.47	0.46	0.31	0.52
Std. Dev.	0.009	0.008	0.19	0.20	0.27	0.20	0.23

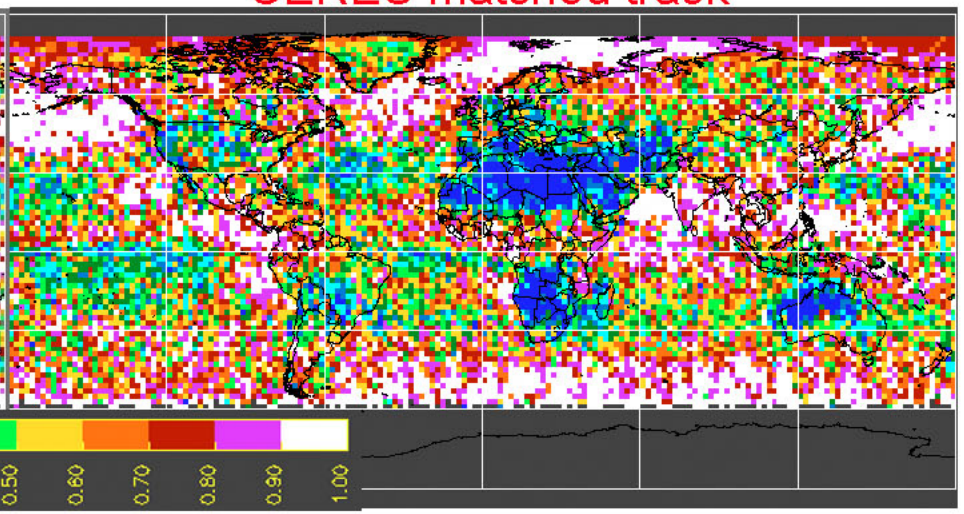
- CERES, DTM, & W&P relationship same as for entire image
- CERES cloud fraction between 1/3 and 1-km high confidence
- CERES Ed3 will be somewhat larger for Cu
- True cloud fraction very elusive
  - CALIPSO will have new values in next release

Along-track Cloud Fractions, CERES vs CALIPSO, July 2006

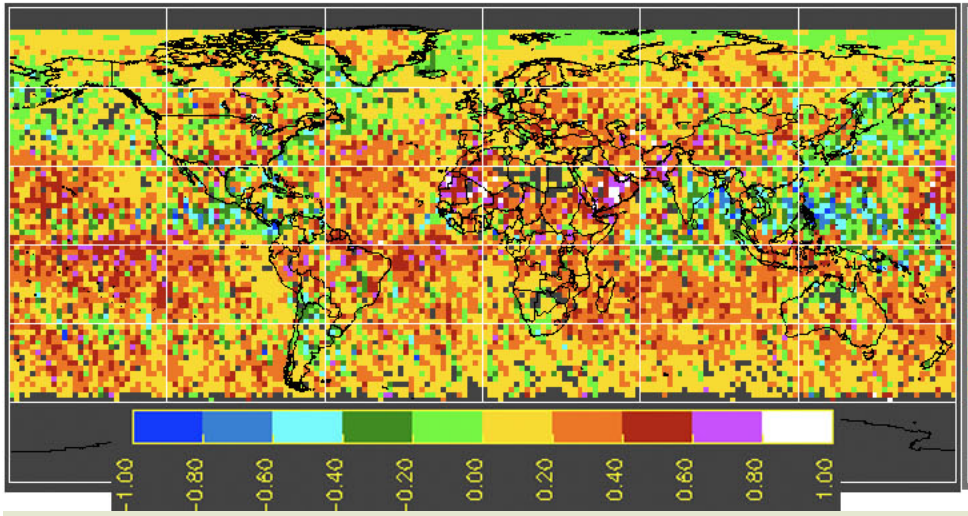
High confidence 1/3km



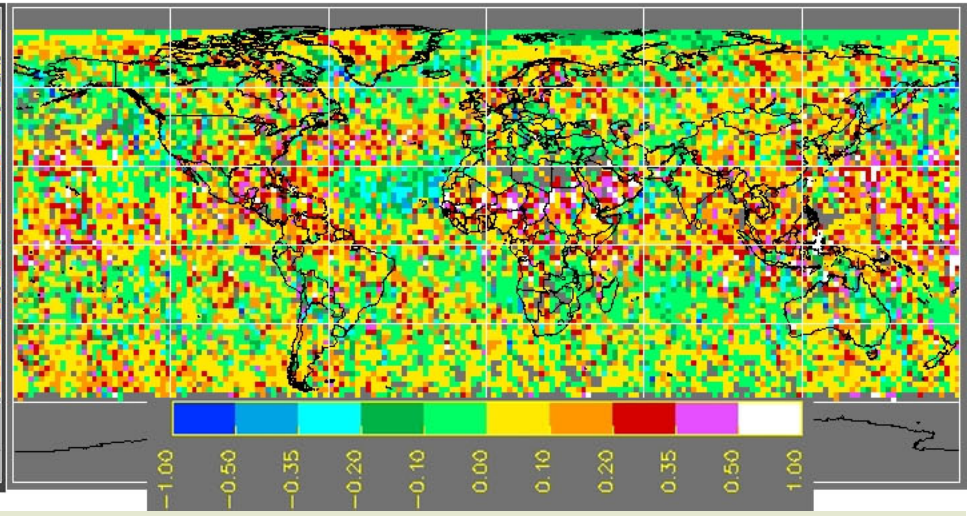
CERES matched track



CALIPSO Std - CERES



Hi-Confidence CALIPSO - CERES



- CERES overestimates severely reduced for hi-con comparison
- Exceptions over Saudi, Sahel, Greenland, TWP

Summary

- 250-m Aqua-MODIS data to determine cloud fraction within each 1-km footprint yields various results depending on threshold
  - What is the best threshold?
- CERES yields mean cloud fractions between high confidence 1 & 1/3 km
  - Much less than all confidence results
  - CERES tends to overestimate cloud amount because of larger FOV for Sc
  - CERES may underestimate cloud fraction for scattered cumulus scenes
  - 250-m MODIS visible reflectance data could help in both cases
    - Many small clouds missed earlier are now detected
    - PROBLEM: viable retrievals for partial pixels not frequent
- Probably stick with 1-km values, but retain hi-res cloud frac info
- Hurry up with new CALIPSO VFM
- Future work – verify inability to effect partial pixel retrievals of tau & Re

Ed 3 Mask Summary

- Considerable number of changes made
  - some made things worse, some better
  - increase in nighttime cloudiness may/may not be accurate
    - need more CALISPO matches
    - if realistic, need increase in daytime

- Beta 2 will have additional changes plus refinements
  - Hi-res VIS
  - adjusted thresholds
  - final CO2 detection
  - altered polar for transition

Final Work for Ed3 Beta2

- Still working on polar cloud fraction discontinuity
  - Tuning cloud mask over Super Cold Plateau
  - Tune Terra mask to new 3.7 calibration
- Revise use of IGBP models - theo over perm snow?
- Examine & tune impact of CO2 retrievals
  - take care of no retrieval cirrus, especially for new detections
- Define lower tau limit of detection w/CALIPSO data
- Reverse nocturnal cloud drop over midlatitudes

RETRIEVALS

• Cloud Retrieval Changes

Single-layer

- CO_2 algorithms: Standard 4-channel; Chang 2-channel (C2C: 11 & 13.3 μm)
  - if VISST/SIST no retrieval, force VISST values to C2C Tcld
- 2.1-μm used for SINT & VINT retrievals for both Aqua & Terra
  - error discovered in Aqua Ed2: 1.6 corr-k's used for 2.1 μm

    Testing ahead with new corr-ks
- zonally averaged ocean/land lapse rates from CALIPSO used for low clouds
  - examining use of combined MOA & lapse rates for low clouds, code error
- improved thick ice-cloud top heights
  - developing new thickness parameterizations
- implemented IGBP-dependent snow albedo models
  - testing revealed some problems
- extended optical depth range to 512
  - still questionable
- initial 2.1-μm particle size retrieval algorithm (VINT), *Testing w/ new corr-ks*
- phase tweaked
  - examining use of mixed CO2/VISST to eliminate cloud edges that are called ice
- partially cloudy pixel algorithm no go at this time

- **Cloud Retrieval Changes**

Auxiliary data

- *updated IGBP map*
- updated elevation map to be delivered

Multi-layer

- C2C (11 & 13.3 *μ*m) ML detection delivered
  - *Chang has reworked this starting from first principles, no empirical corrections*

- BTD (T11 – T12) algorithm delivered, notes ML detection, not a retrieval

- C2C ML retrieval algorithm: iteration on De (size for high & low clouds)

Cloud Heights

- CERES Ed2 Satellite Retrievals Use $Z_c = z(T_c)$

  - $p > 700$ hPa, $Z_c = (T_c - T_{sfc}) / \Gamma$

    - for ocean, T_{sfc} = SST
    - for land, T_{sfc} = 24-h running mean T_{skin}(model)

  - $p < 500$ hPa, $Z_c = z(T_c)$, where z(T) is NWA (e.g.,GEOS-5)

  - $500 < p < 700$ hPa, Z_c = avg of the above two

  Z_c, T_c = cloud effective height, temperature

  Γ = -7.1 K/km *(Minnis et al., JAM 1992)*

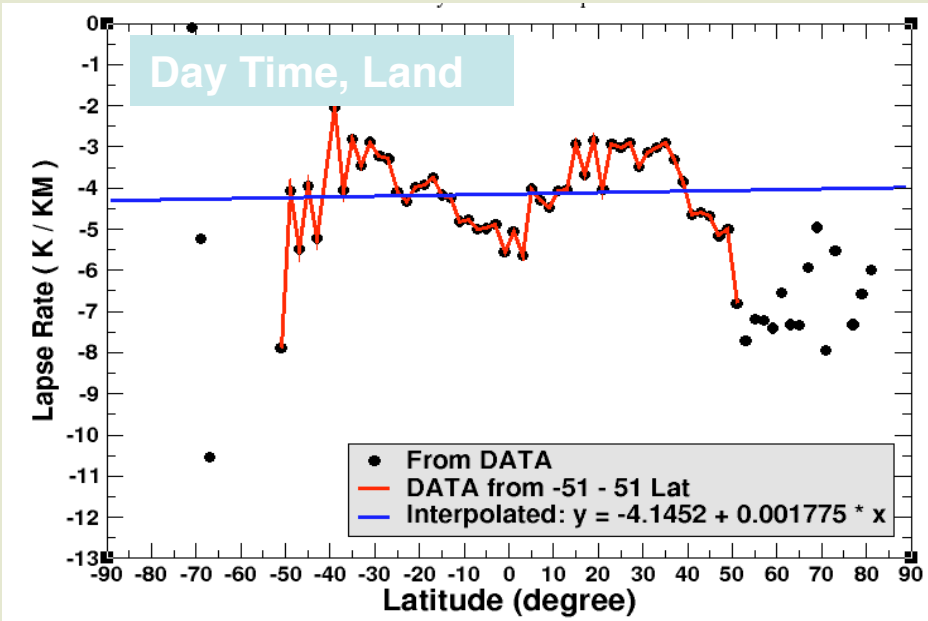
- CERES Ed3 beta 1 uses $\Gamma = \Gamma$(lat, sfc type) based on 1 month of CALIPSO-MODIS comparisons

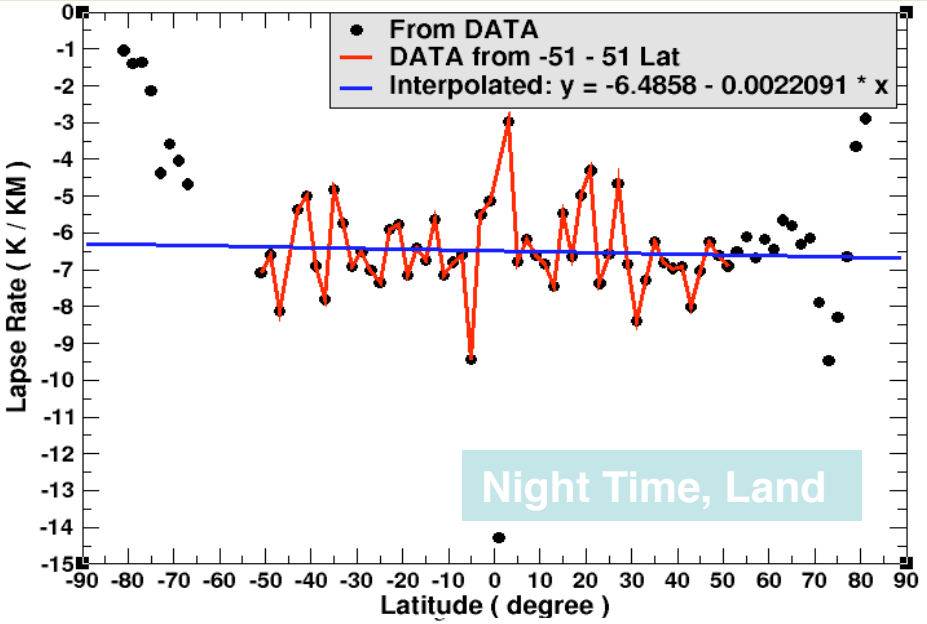
- New empirical lapse rate developed by Zuidema et al. (2008)

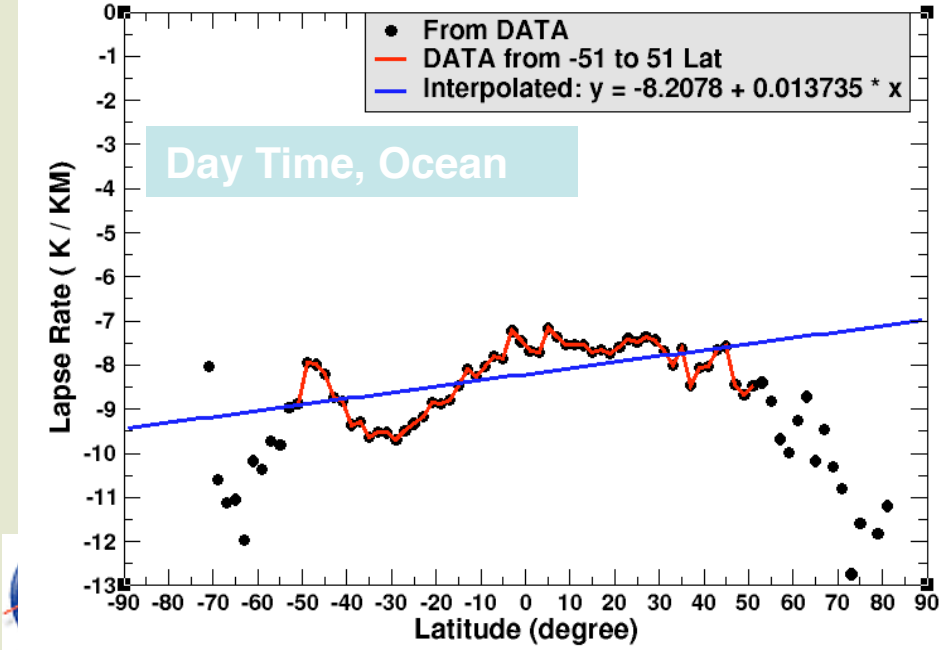
  - $Z_c = [\, T_{sfc} - T_c - 2.35\ \text{K}] / 0.0069$

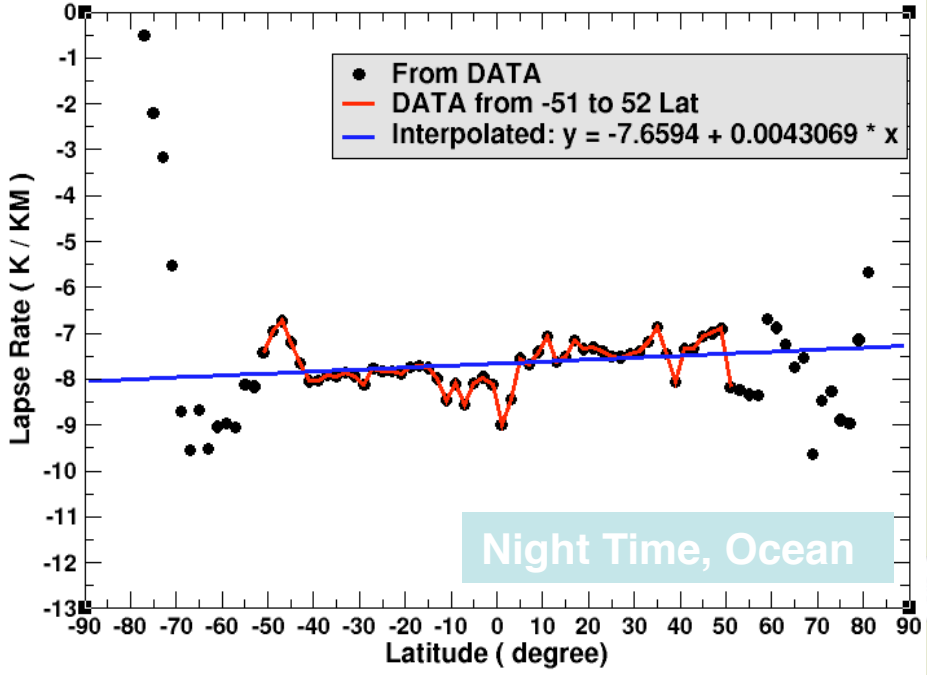
We plan to examine this type of fit to reduce errors for low clouds.

Zonal Lapse Rate (April 2007)









Lapse rate summary

- **Ed3 beta 1 had coding error, so decrease in low cloud height over land not accurate, will rerun**

- **Newer approaches could reduce std & regional biases**
  - *repeat Zuidema approach using matched MODIS & CALIPSO data for several months; examine regional & sfc type fits,* ***now have the data***
  - *test results using independent month*
  - *examine use of minimum Z from GEOS-5 or lapse rate*
  - *redo Dong study over SGP*

- **examine cloud temperatures and lapse rates over polar regions**

- Now have 4 months of matched CC & MODIS data to test these new methods

Cloud Property differences between Ed β1 – Ed2

Terra MODIS, July, 2006, non-polar

	Ocean	Land
Re (μm)	0.5	0.8
De (μm)	3.0	3.0
Zwater (km)	-0.3	-0.4
Zice (km)	1.2	1.2

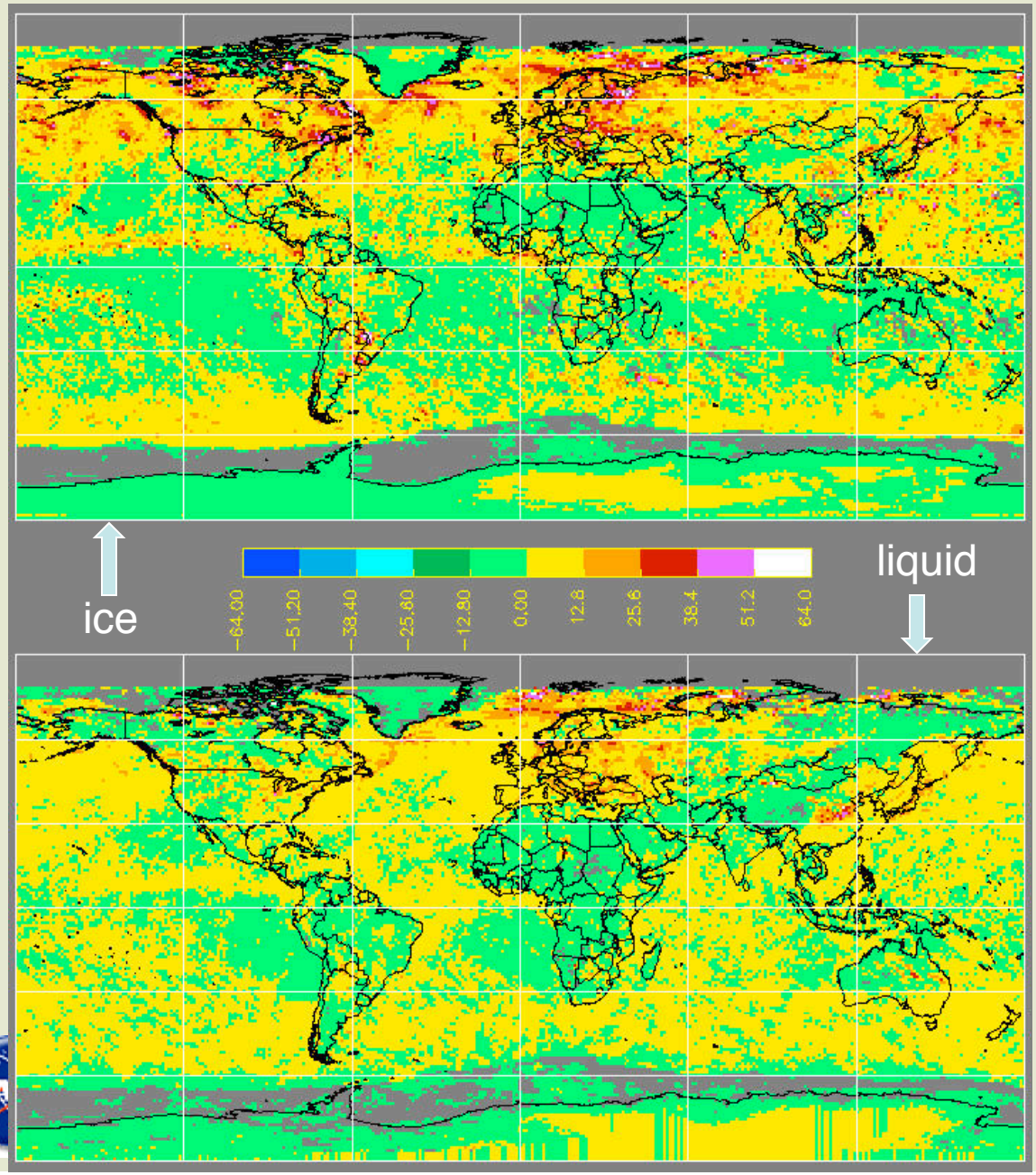
- particle size changes due mainly to change in Terra 3.8-μm calibration, expected

- liquid cloud heights went down over both land & ocean
  - error in code
  => land wrong

- ice increase mainly due to using CO2 height and forcing the optical depth in VISST

Cloud optical depth differences between Ed β1 – Ed2

Terra MODIS, July, 2006, non-polar



- main change is increasing range from 128 to 512

  - drastically increases mean optical depth & IWP particularly at large SZA

Edition 3 Retrievals of Thin Cirrus Cloud Properties, Daytime

- Perform VISST & CO_2-slicing retrievals

  => T_{eff}, τ_{sm}, p_{eff}, D_{sm} + T_{co2}, p_{co2}, τ_{co2}

- If single-level and $\tau_{sm} < 6$, then

  - if $p_{eff} - p_{co2} > 50$ mb, then attempt to find new ice crystal model

- Perform retrieval with VISST-R, where nominal models replaced with roughened models, $\sigma = 1.0$: => T_{reff} , g_{ro}, τ_{ro}, D_{ro}

- If $T_{co2} \leq T_{reff}$ then use results of VISST-R, otherwise

$$\tau = (\tau_{sm} - \tau_{ro})/(T_{eff}-T_{reff}) + \tau_{ro}$$

And so forth for g, D_{eff}

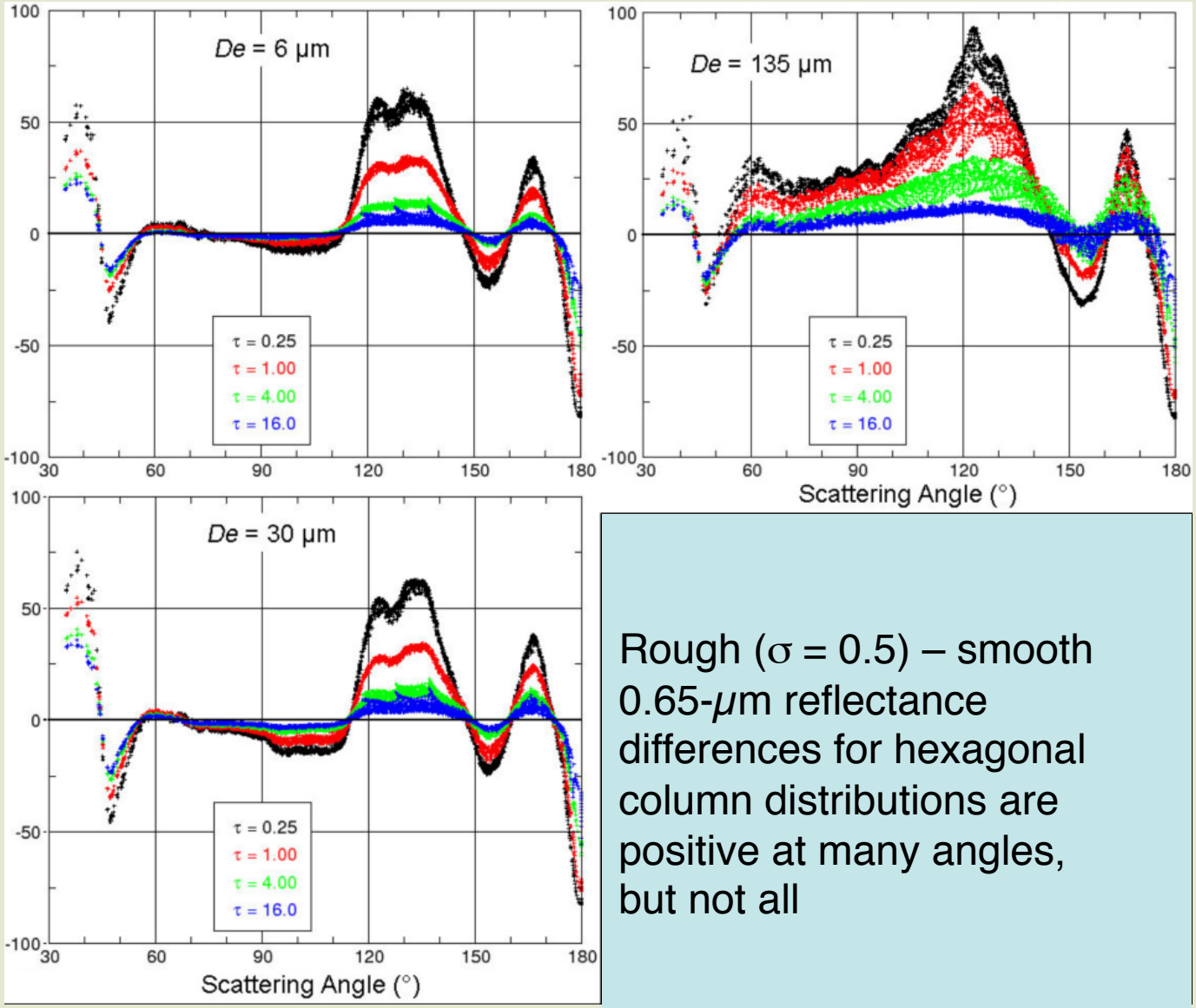
- Retrieval structure implemented without the models

  - now force τ to yield τ_{co2}

  - code to use models being tested

Reflectance fields for smooth & roughened ice hexagonal columns

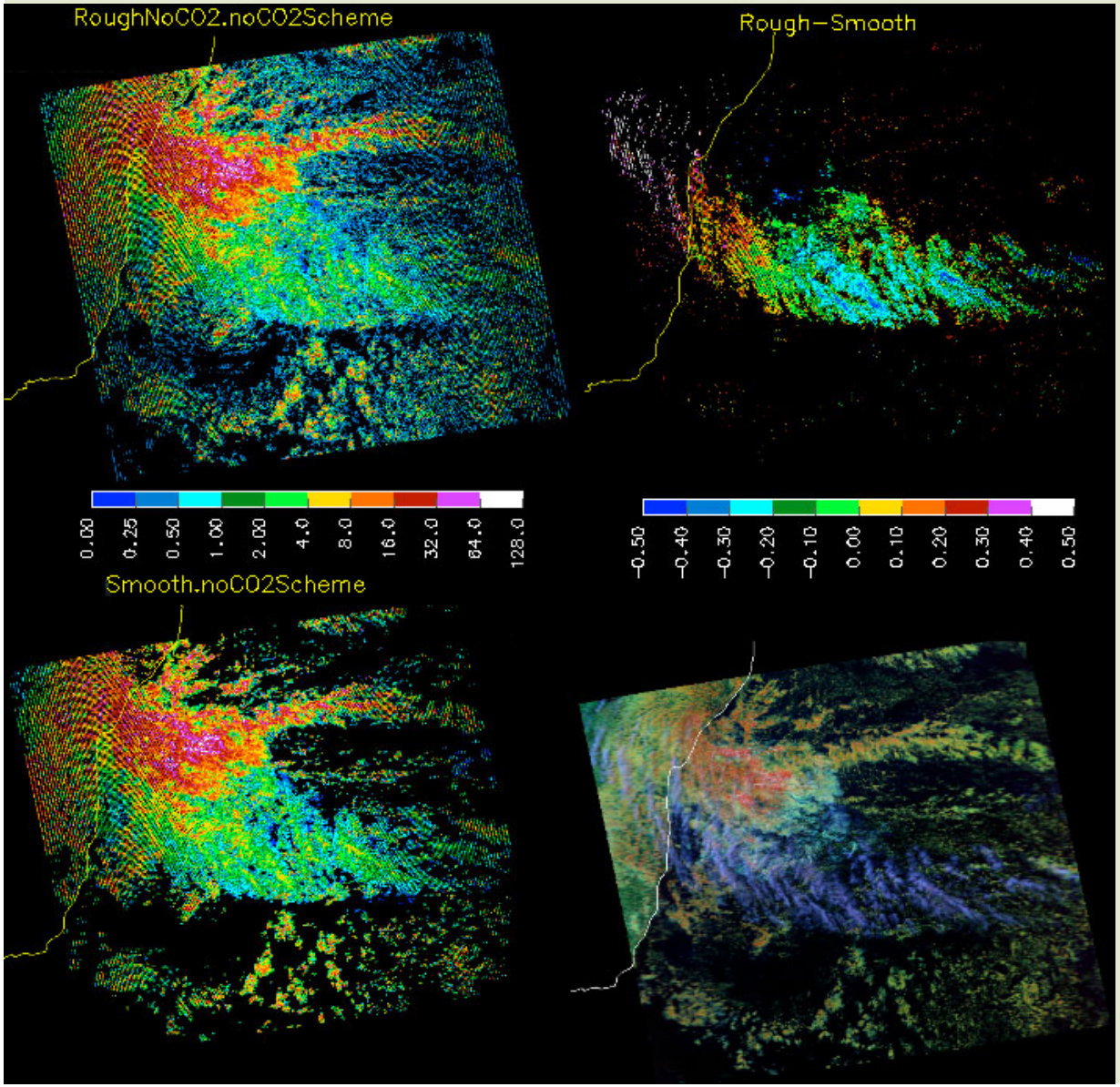
Change in reflectance depends on De and τ



Rough ($\sigma = 0.5$) – smooth 0.65-μm reflectance differences for hexagonal column distributions are positive at many angles, but not all

Impact of Rough Ice Crystal Model on τ Retrieval, Aqua, 15 July 06, 15 UTC

σ = 1.0

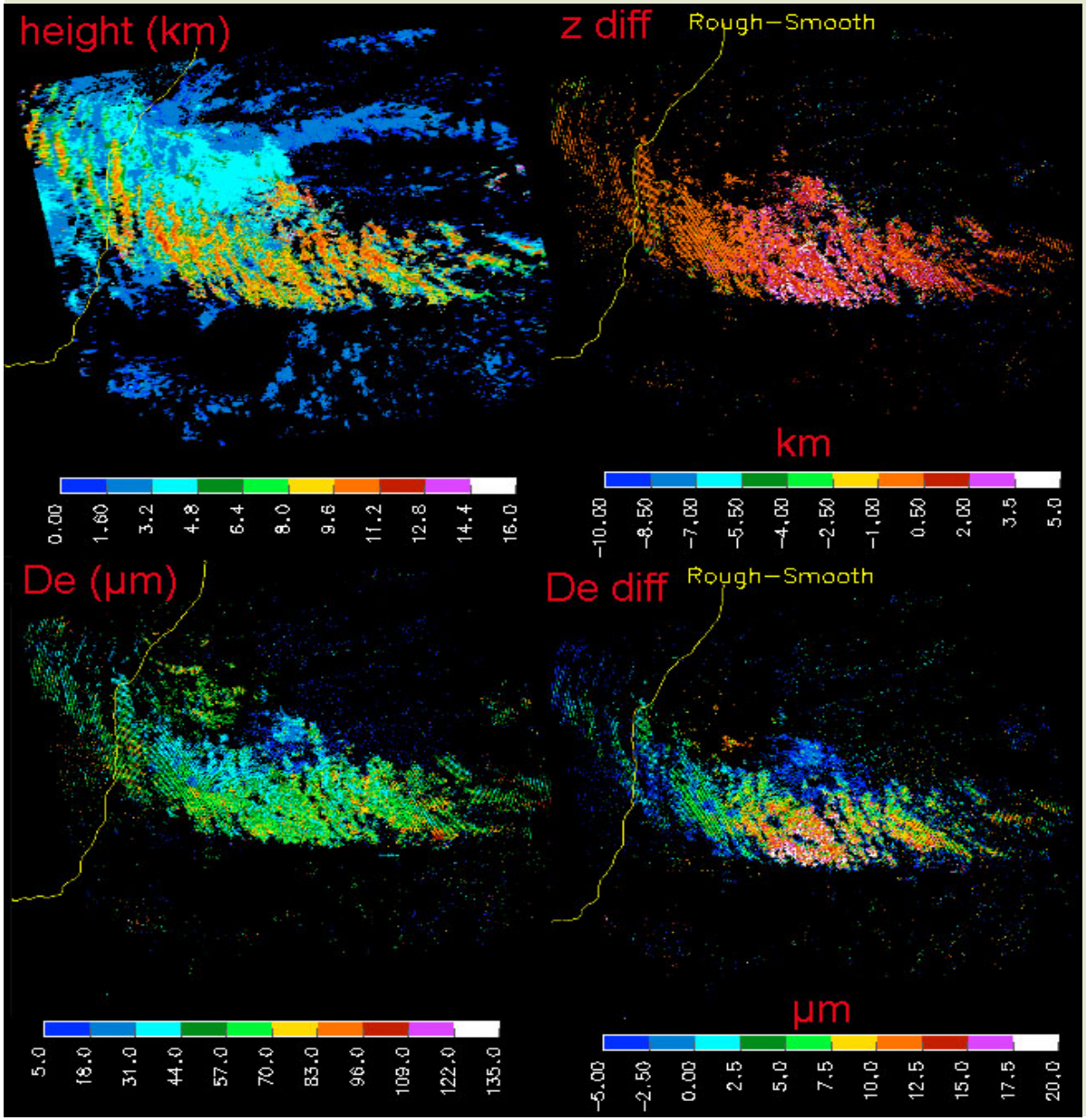


- Scan angle changes from > 90° to < 90° near center of image going right to left

- tau decreases on right side & increases on left, except near edges of cloud

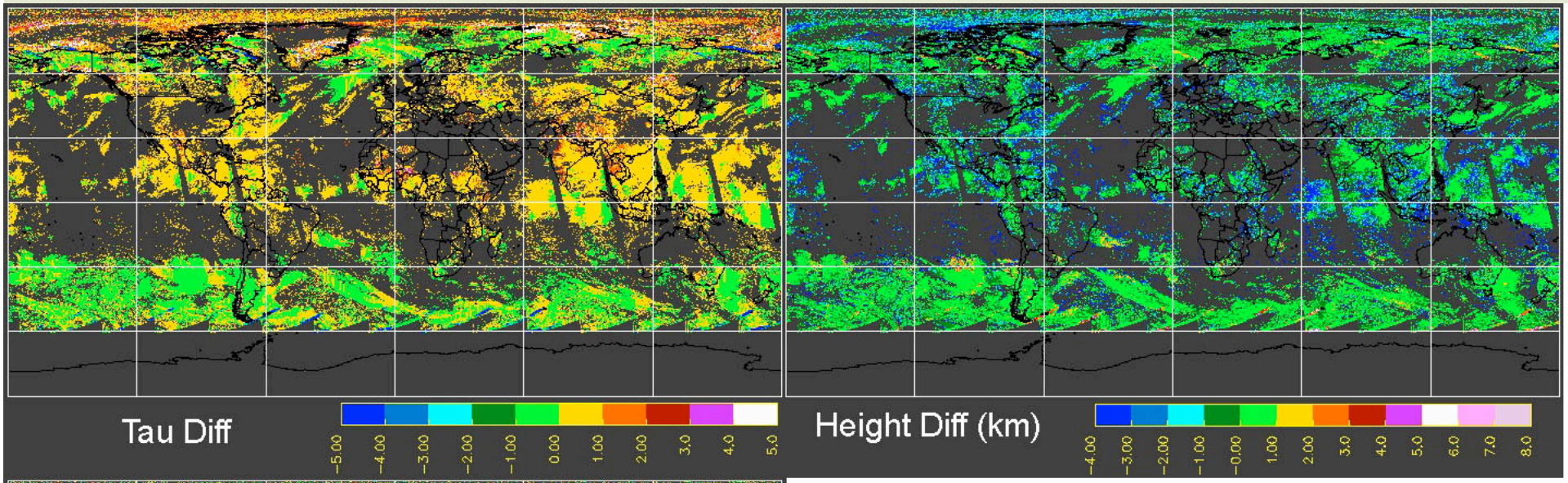
Impact of Rough Ice Crystal Model on z & De Retrieval, Aqua, 15 July 06, 15 UTC

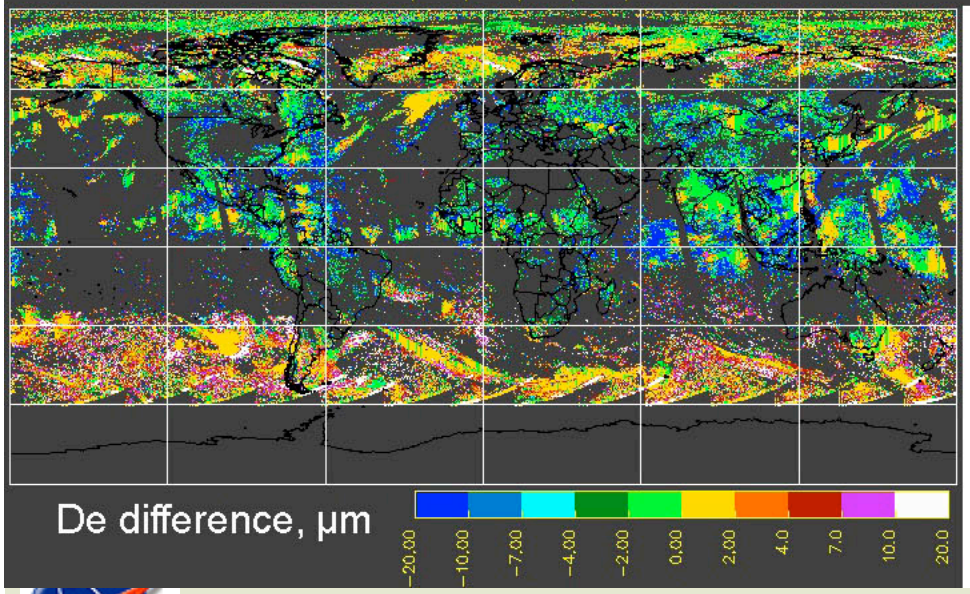
$\sigma = 1.0$



- Where tau decreases, z increases or stays equal
- De increases where tau decreases & vice versa
- De decreases where De(smooth) is very small to begin with

Impact of Rough Ice Crystal Model on z & De Retrieval, Aqua, 15 July 06



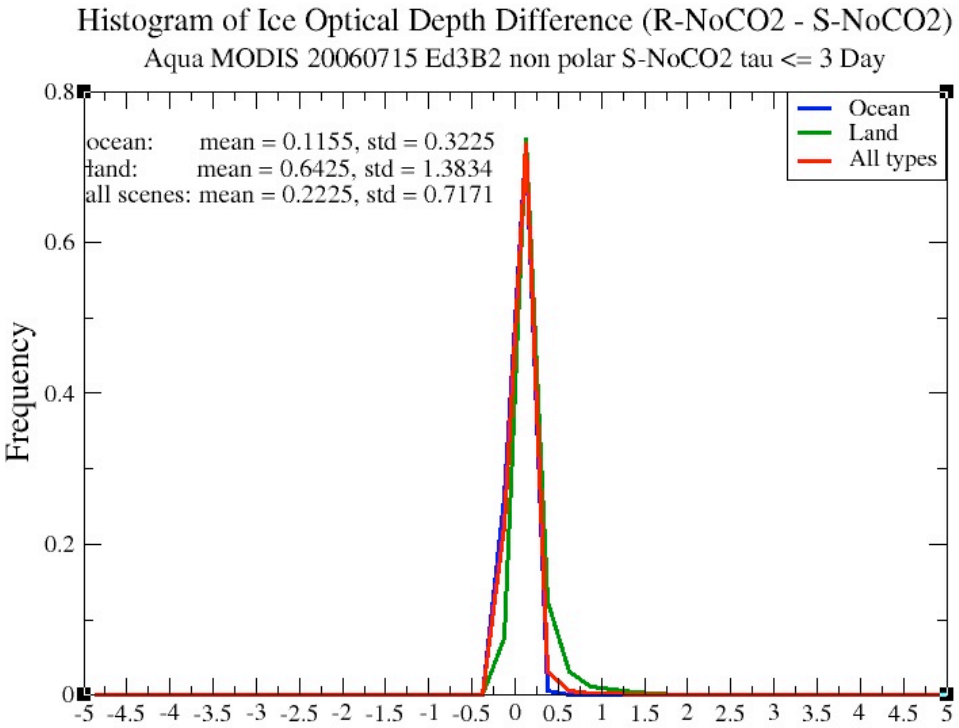


- tau difference mostly negative in SH & on eastern side of scan
- height follows inverse of tau difference

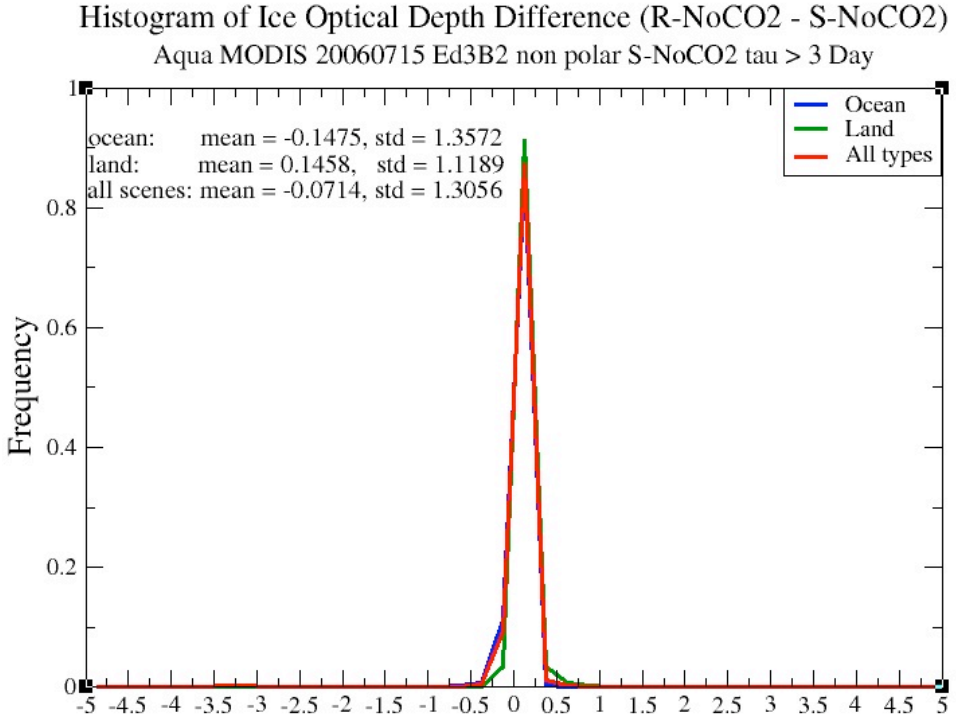
- De changes are significant, but tend to complement tau change so IWP differences likely to be small

Optical Depth Differences, Rough – Smooth, Aqua, 15 July 2006

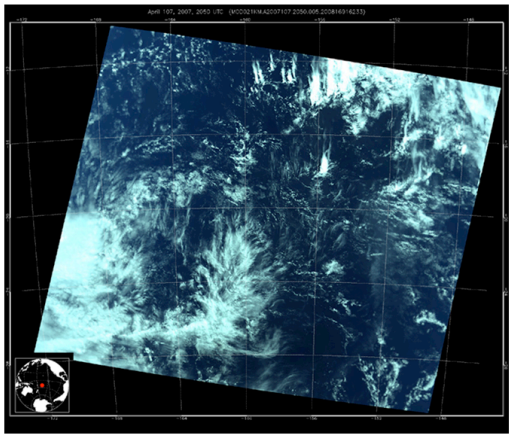
$\tau(\text{smooth}) \leq 3$

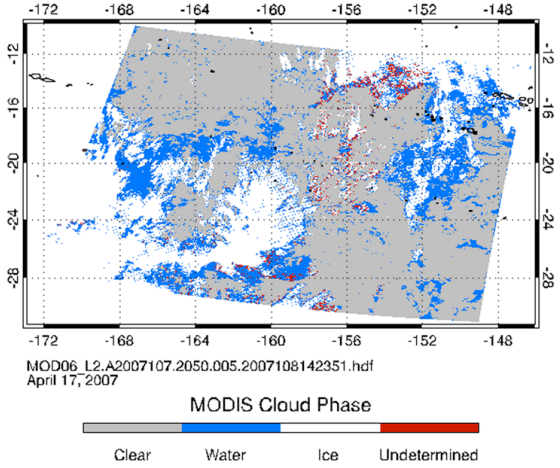


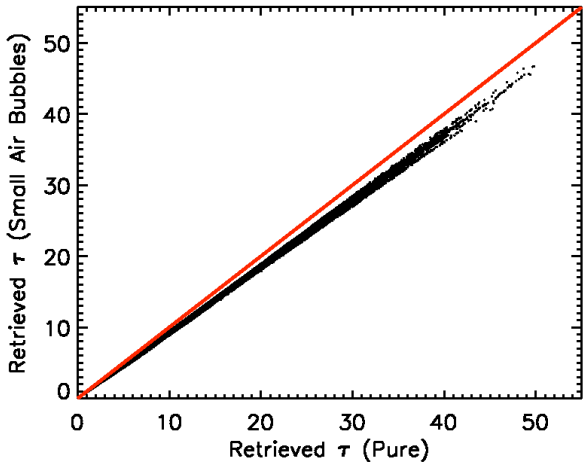
$\tau(\text{smooth}) > 3$

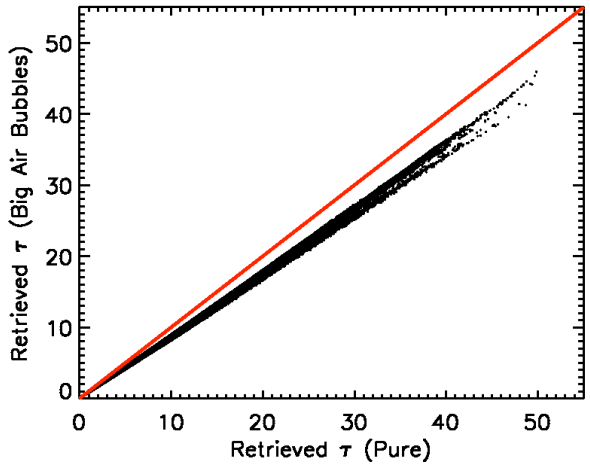


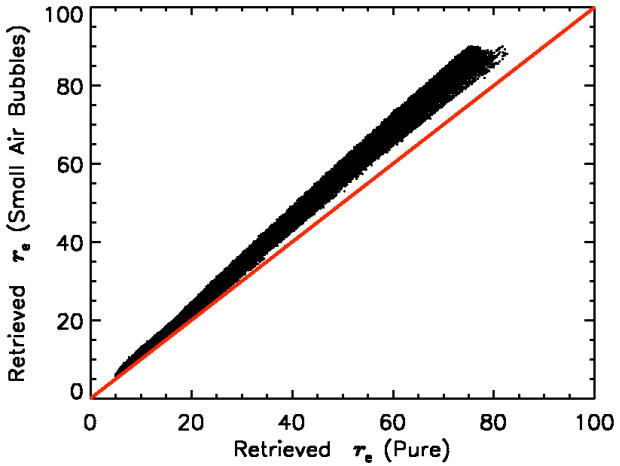
- Overall, tau increases for target clouds ($\tau < 3$), decreases for thick clouds
  => not what we need

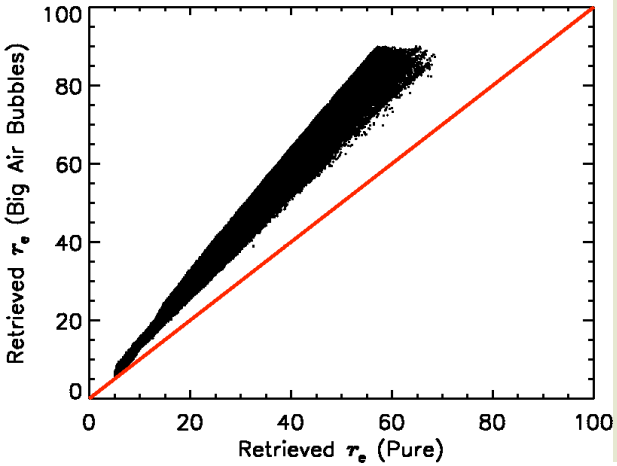












Another Crystal Model?

Bubbles also reduce g, but it appears that the tau drops and De increases on both sides of the scan

Models will be tested, now that framework is set up.

Xie et al., *JGR*, 2009

Edition 3 Improvement of SIST Retrievals, Night/Twilight

- Perform SIST & CO_2-slicing retrievals

  => T_{eff}, τ_{sm}, p_{eff}, D_{sm} + T_{co2}, p_{co2}, τ_{co2}

- If single-level and $\tau_{sm} < 6$, then

  - if $p_{eff} - p_{co2} > 50$ mb, then attempt to find new ice crystal model

- Perform retrieval with SIST-C, where $T_{reff} = T_{co2}$, solve for τ, D_{eff}

- Retrieval structure has been developed and is in Ed3 Beta 1

  - results to be statistically analyzed when CC-matched dataset available

Cloud Thickness

• Used to estimate physical tops and bottoms of clouds for radiation calculations

- fills volume of atmosphere with cloud

• Empirical fits used to estimate cloud thickness separately for low water clouds and ice clouds, and interpolated between

- Ed2 fits based on relationships developed over ARM SGP

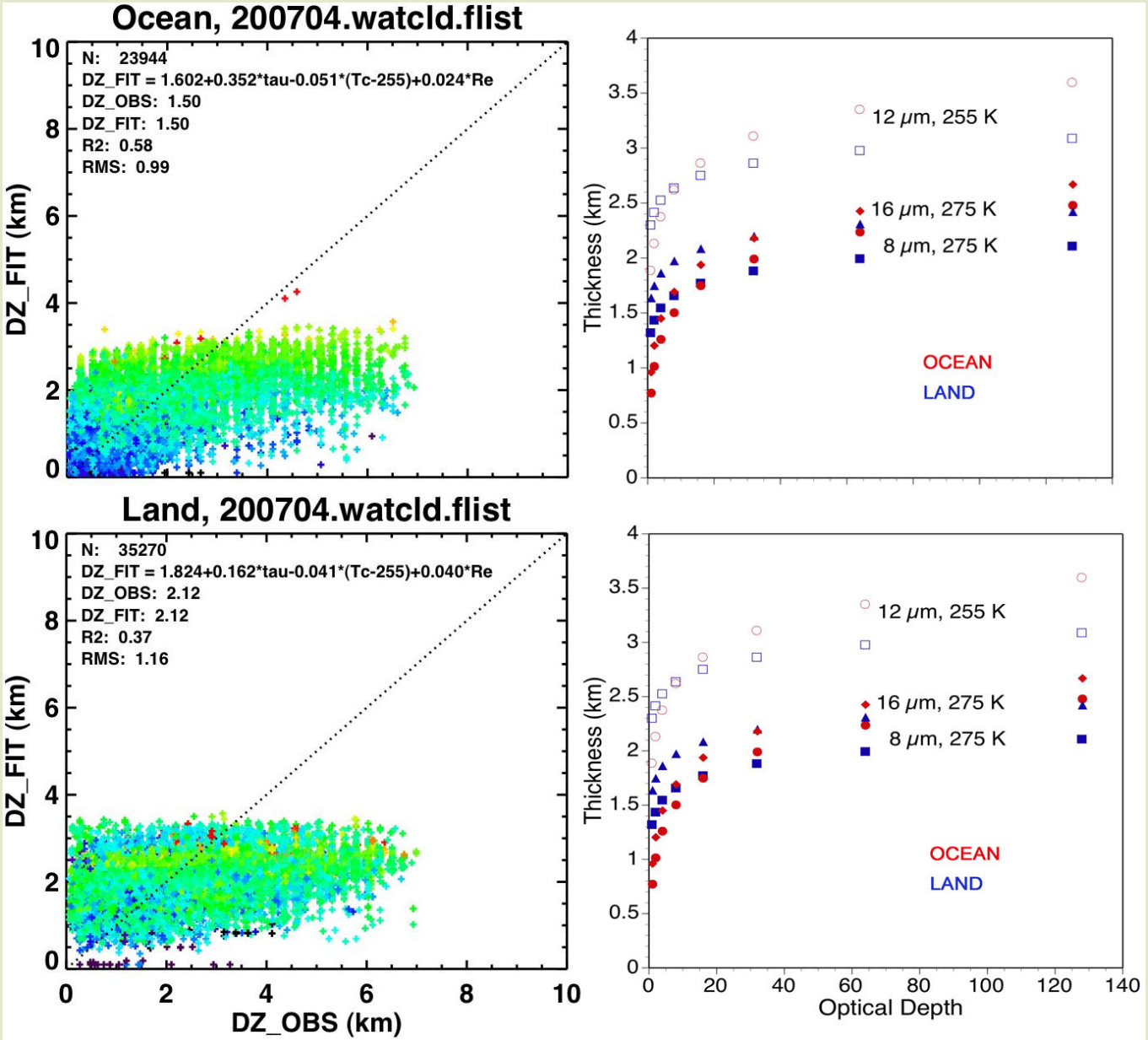
limited data, limited cloud types

• CloudSat/CALIPSO data

- new opportunity to verify/improve the fits
- 2 months of data used: July 2006, April 2004
- single-layer clouds only, nonpolar

Liquid Clouds: New fits vs. CALIPSO/CloudSat Thicknesses, April 2007

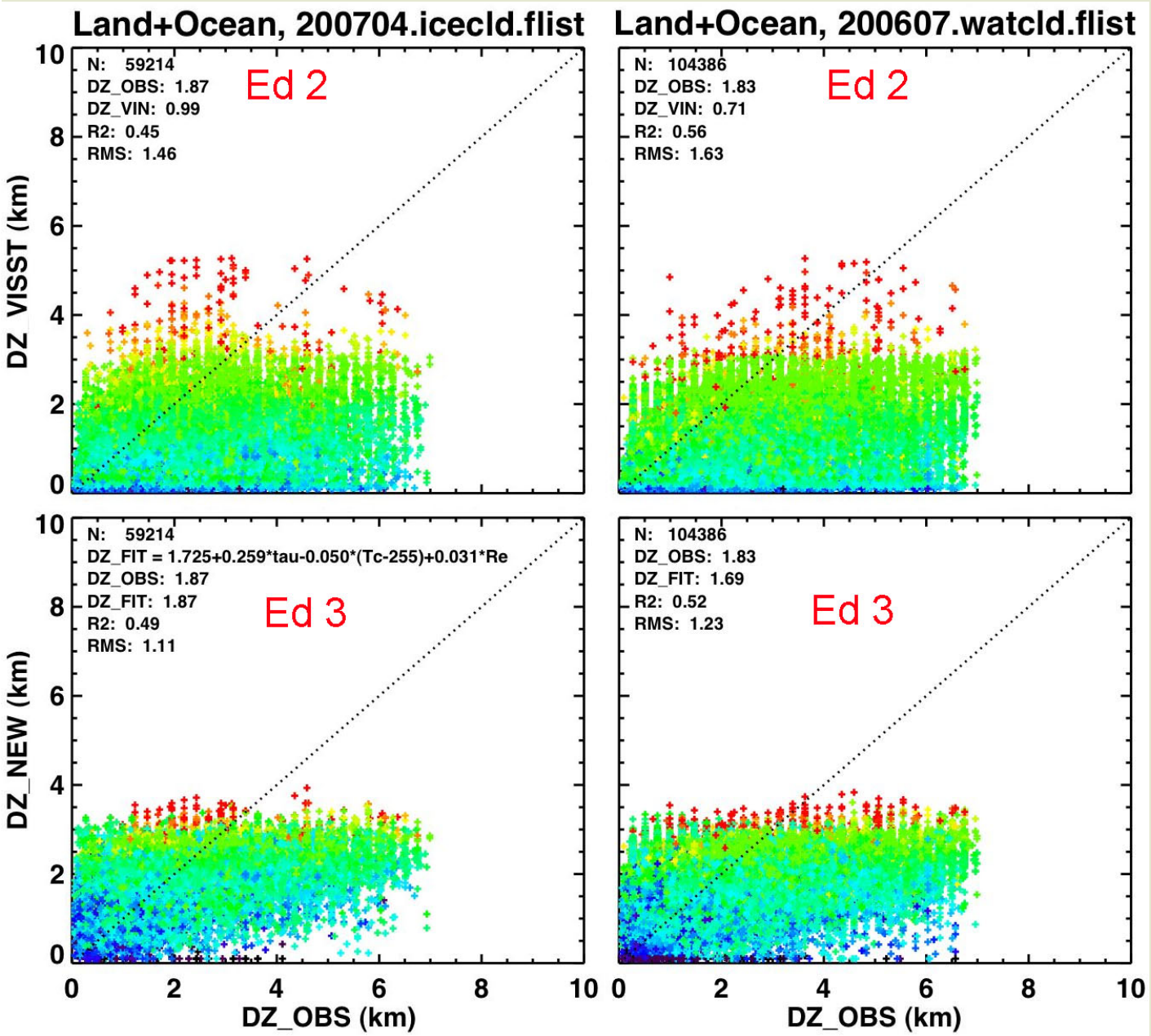
$\Delta Z = \Delta Z\,[Tc, \ln(\tau), Re]$



Liquid Clouds: Ed2 and new fits vs. CALIPSO/CloudSat Thicknesses

Used for fits, April 2007

Used fits, July 2006



Regression fit based on SL clouds with base > km, during April 2007, RMS similar to Ed original regression

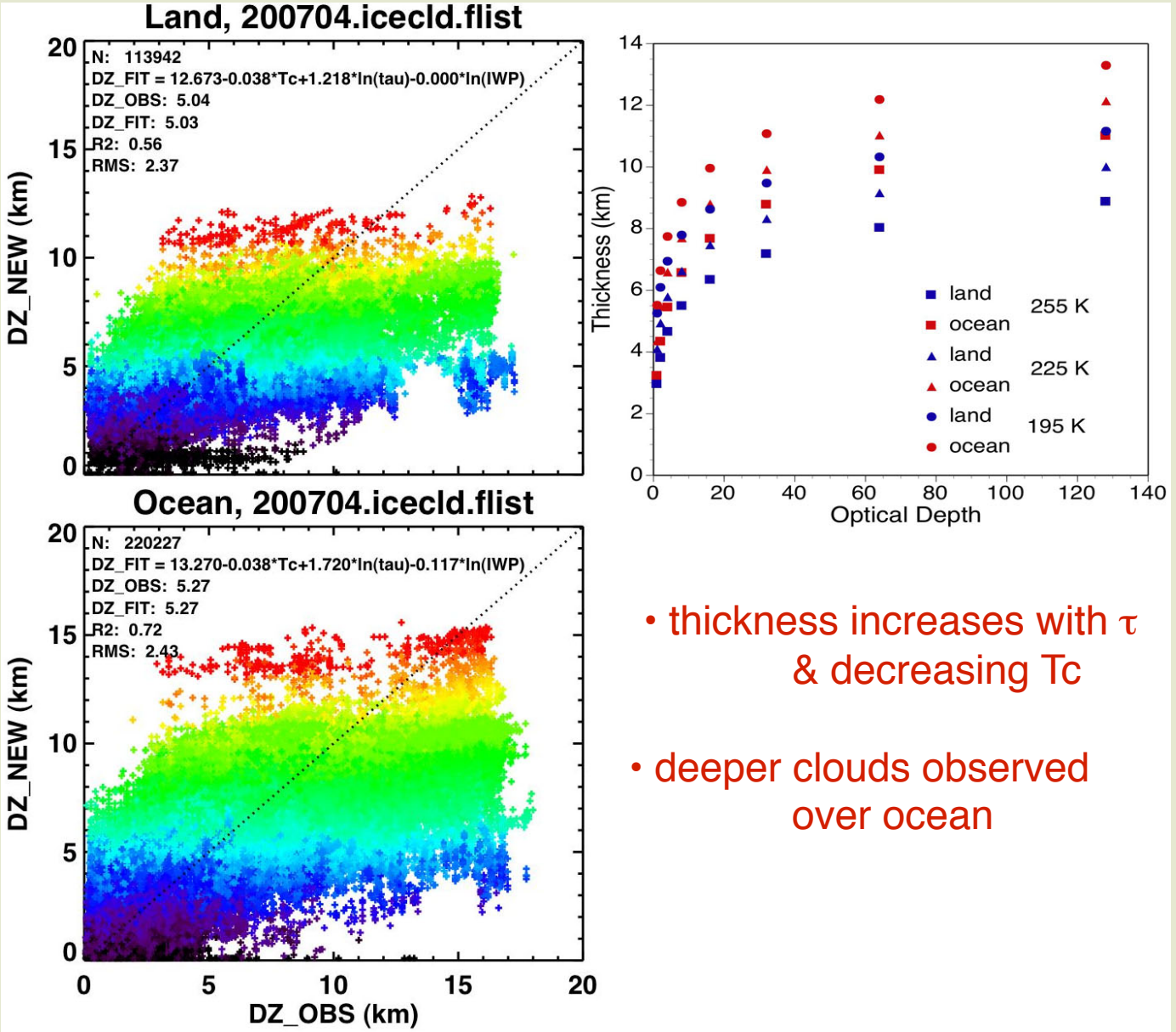
Ed 3 results for July 2006 verify robustness of fits

delZ = 0.14 km

Rms = 1.23 km

Ice Clouds: New fits vs. CALIPSO/CloudSat Thicknesses, April 2007

$\Delta Z = \Delta Z\,[Tc, \ln(\tau), \ln(IWP)]$

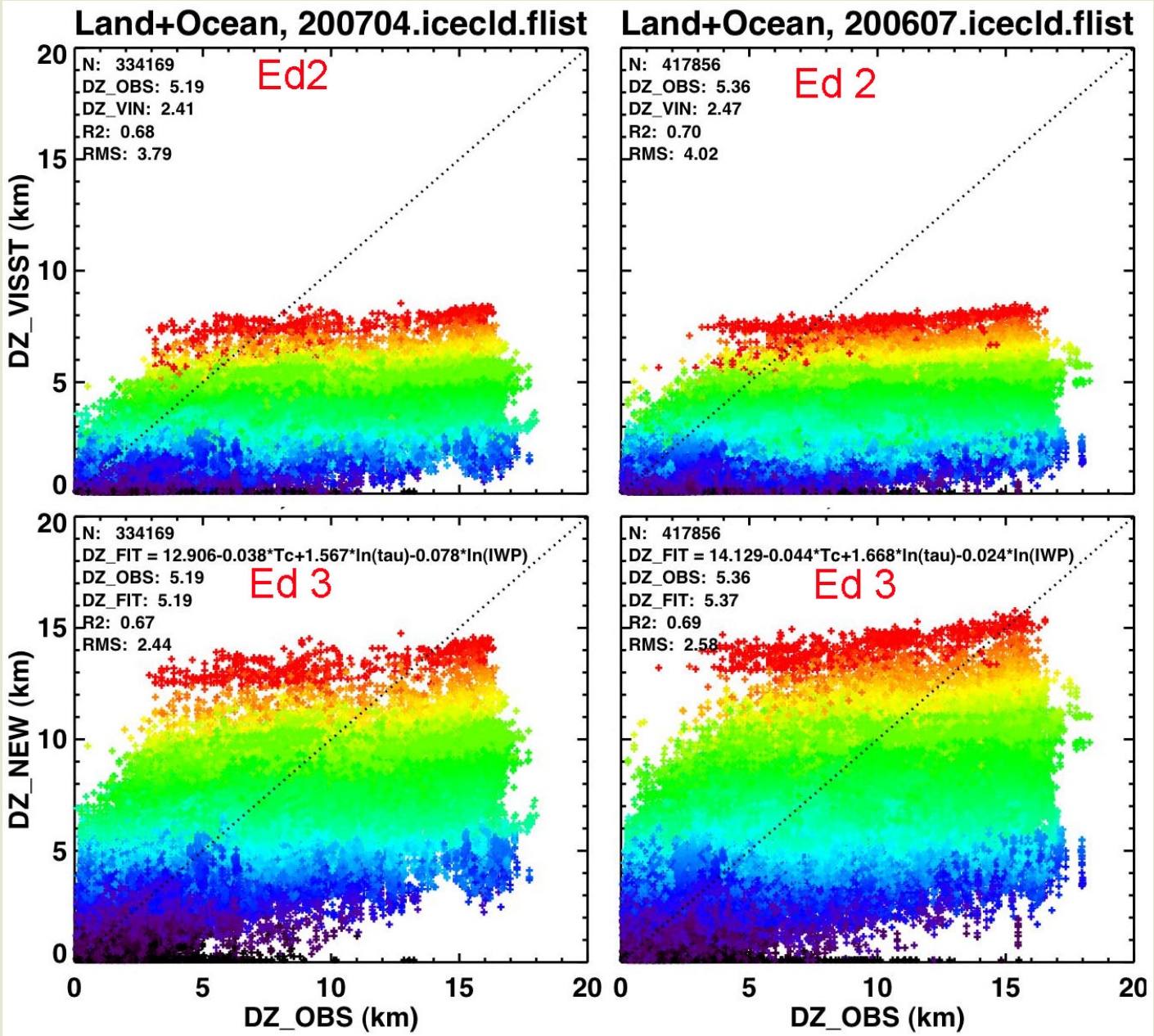


- thickness increases with τ & decreasing Tc
- deeper clouds observed over ocean

Ice Clouds, Ed2 and new fits vs. CALIPSO/CloudSat Thicknesses

Used for fits

Used fits



Regression fit based on SL clouds during April 2007, RMS not wonderful

Ed 3 results for July 2006 verify robustness of fits

delZ = 0.01 km

Rms = 2.58 km

No Retrieval Minimization

- CERES Ed2 no retrieval fraction
  - Aqua = 0.036
  - Terra = 0.048
  - difference mainly in polar regions, *error logic in Terra Ed2*
- To reduce no retrievals in Ed3
  - fix error logic in Terra Ed2 as done in Aqua
  - use LBTM (VIS & IR only, assume particle size)
  - use IR (CO2) techniques for thin clouds
  - use high-res data for partially cloudy pixels
- Test runs indicate LBTM reduces no retrievals to < 1%
  - IR techniques (SIST/CO2) needed for remainder
    - recalculate clear-sky reflectances/sfc temps?

CO_2 & Multilayer Methods

- Applicable to SL & ML clouds both day and night
- Faster than 5-channel method
- Applicable to many satellites (any imager with 11 and 13.3 μm)
- Using new Chang code for 2-channel method
- BTD & CO2 techniques - ~85% accurate in detecting SL clouds

  - minimal skill at detecting ML clouds (~ 50%)

- both will be retained in Ed3

Edition 3 Betas

- **Cloud mask improvements**
  - C2C method working;
  - clear-sky model, threshold, polar transition improvements
    - *more work needed, need more eval of CALIPSO CFs*
- **Cloud retrieval improvements**
  - multispectral retrievals *look good*, fewer no retrievals
  - improved lapse rates w/ blended C2C heights => *better heights*
  - new ice cloud phase functions: *rough/bubbled xtals in Beta 2*
  - expanded tau range: *cut back to a smaller max?*
  - polar retrievals: *turn on SINT for Terra*
- **Multilayer cloud detection & retrieval**
  - New code working: *see Chang talk*
  - CALIPSO opt depth now available for assessment
- **Hi-res cloud detection/retrieval of low clouds, maybe not** *Beta 2*
- **New thickness parameterization**: *Beta 2*
- **Continue work on BTD ML method**: *NPP (no CO2 on VIIRS)*